ELECTRICIAN'S MATE 3

NAVY TRAINING COURSES

NAVPERS 10548

ELECTRICIAN'S MATE 3

PREPARED BY
BUREAU OF NAVAL PERSONNEL

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PREFACE

This book is written to aid the striker for Electrician's Mate 3 to qualify for advancement to that rate. The combination of this Training Course and practical experience will enable the striker to meet the official requirements for advancement to EM3. These requirements, as given in *The Manual of Qualifications for Advancement in Rating* (NavPers 18068), are reproduced in appendix II.

This course is based on an elementary knowledge of electricity and mathematics. Therefore, before starting this course the striker should complete the two basic Navy Training Courses, *Electricity*, NavPers 10622, and *Mathematics*, Vol. 1, NavPers 10069, and *Mathematics*, Vol. 2, NavPers 10070.

The duties of an Electrician's Mate also require an elementary knowledge of machines, tools, and blueprints. Hence, while studying this course, the striker should review these additional basic Navy Training Courses—*Basic Machines*, NavPers 10624; *Use of Tools*, NavPers 10623; and *Use of Blueprints*, NavPers 10621.

This training course presents the basic phenomena of direct current necessary for an EM3 to perform his duties on direct current machinery. He should also have a similar background on alternating current machinery. Such background he will find in the appropriate chapters of the Navy training course for *Electrician's Mate 2c*, NavPers 10103.

As one of the NAVY TRAINING COURSES, this book represents the joint efforts of the Training Publications Section of the Bureau of Naval Personnel and of those Naval establishments specially cognizant of the technical aspects of Electrician's Mates' duties.

READING LIST

NAVY TRAINING COURSES

Electricity, NavPers 10622
Mathematics, Vol. 1, NavPers 10069
Mathematics, Vol. 2, Nav Pers 10070
Electricity for Fire Controlmen and Fire Control Technicians, Vol. 1, NavPers 10041–A
Electricity for Fire Controlmen and Fire Control Technicians, Vol. 2, NavPers 10041–B
Basic Machines, NavPers 10624
Use of Tools, NavPers 10623
Use of Blueprints, NavPers 10621
Electricians Mate 2c, NavPers 10103.

OTHER NAVY PUBLICATIONS

BuShips Manual, Chapters 60, 61, 62, 63, 64, 65, 66, and 69.

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

Number	*Title*
J 313	*Elementary Electricity*
EM 400	*Physics I (Mechanics)*
EM 404	*Physics III (Electricity)*
EM 416	*Electricity for Beginners*
EM 970	*Mathematics for Technical & Vocational Schools*
EM 975	*Electric Wiring*

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

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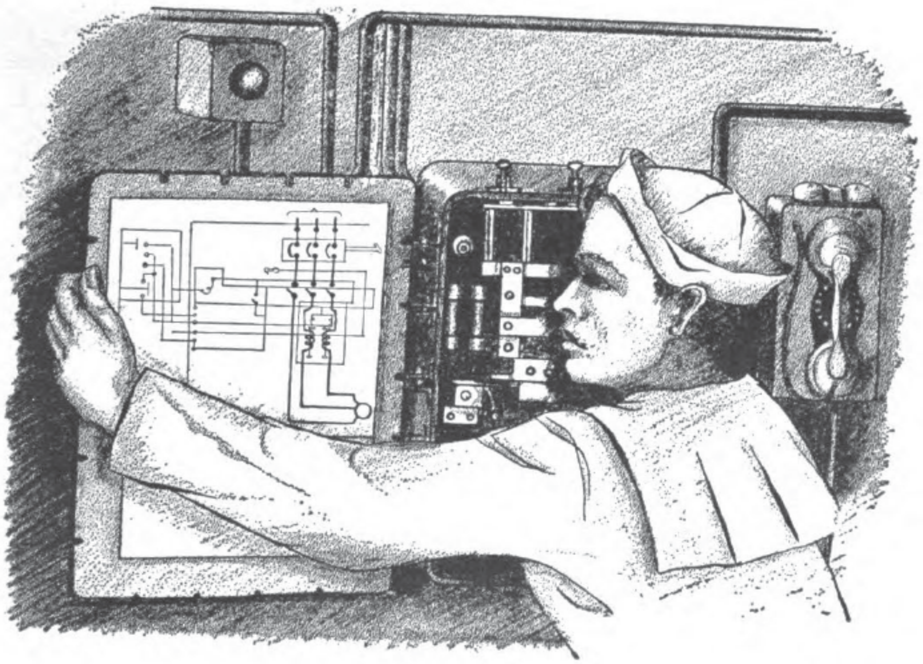
STUDY GUIDE

If you are in the Regular Navy, you will be striking for the general service rating (EM). To meet the qualifications for 3rd class in this rating (see column EM, appendix II) you will have to study all the chapters in this book.

If you are a member of the Naval Reserve you will be striking for either the emergency rating as power electrician (EMP) or shop electrician (EMS). To meet the qualifications for EMS you have to study all the chapters of this book except chapter 11 (D-C Controllers). For EMP3 rate you have to study all the chapters except chapter 10 (Maintenance of Direct-Current Motors and Generators). However, to gain a well-rounded view of the duties of the general service rating, it is recommended that you also read the additional chapters 10 or 11, which do not pertain directly to your rating.

ELECTRICIAN'S MATE 3



CHAPTER 1

ELECTRICAL CURRENTS AND CIRCUITS—OHM'S LAW

ELECTRICITY, AN INVISIBLE SERVANT

Most of you have had some experience with electricity. Possibly your experience was limited to replacing a blown fuse or burned-out light bulb. If you were a top-notch amateur, you may have done some wiring about your home; but now you are about to become an Electrician's Mate, and it is necessary for you to learn the Navy's way of doing things. This manual will start you off on the right foot. If you must change your method of making electrical connections, installing switches, or operating motors, don't be upset—the men of the Navy have learned by experience the best way of doing the job.

Electricity is known by what it does (producing light, running motors, and operating telephones) rather than by what it is. While there may still be some doubt as to what electricity is, the laws governing what electricity does are well known and clearly defined.

Electricity can be your slave, or your master. If you learn the laws of electricity well, and respect its abilities, it will work for you in a thousand and one ways. But if you are careless, and do not learn what electricity is capable of doing, it may destroy you.

THIS COURSE AND YOU

This course is not intended to make a designing engineer out of you. Instead, it is to acquaint you with the basic laws of electricity, and to teach you how to apply them in operating and maintaining the electrical equipment on your ship.

This book starts where the course on Basic Electricity leaves off. You will find the contents much easier to master if you will first review the course on *Basic Electricity* (Navpers 10622).

As an Electrician's Mate you are principally concerned with electrical circuits. To start you off right, this chapter will give you a quick review of the basic ideas about electrical circuits that you have already learned from your study of elementary electricity.

ELECTRICAL CURRENT IS LIKE WATER IN A PIPE

An electric current is a flow of electrons through a conductor. Therefore, current electricity can be compared to water flowing through a pipe.

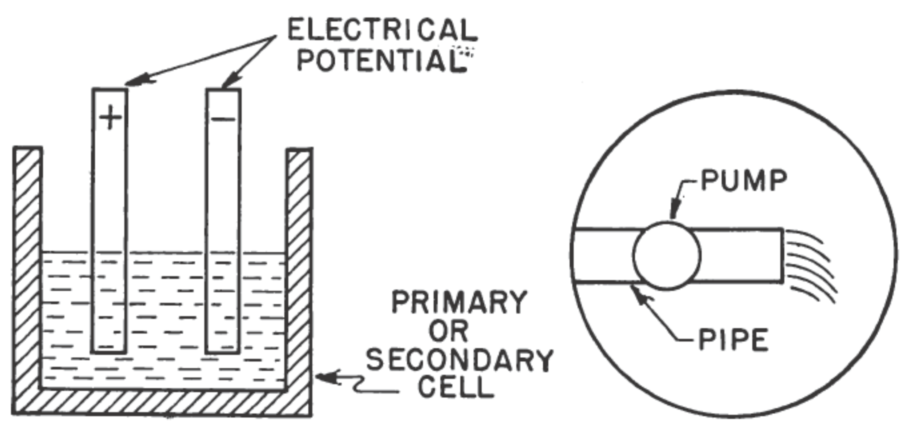


Figure 1.—A source of electrical potential.

Before an electrical current can flow, there must be a source of electrical pressure, just as you must have a pump to build up water pressure. This electrical pressure is called an ELECTROMOTIVE FORCE and is produced by a battery or a generator. The electrical pressure between any two points in a circuit is called the POTENTIAL. Look at figure 1. The cell plays the same part in causing a current to flow as the pump does in forcing water through the pipe.

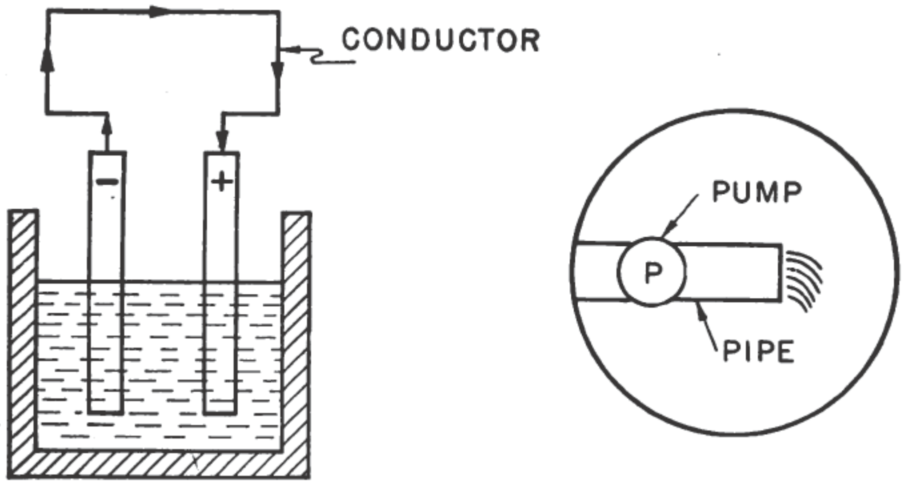


Figure 2.—Conductors.

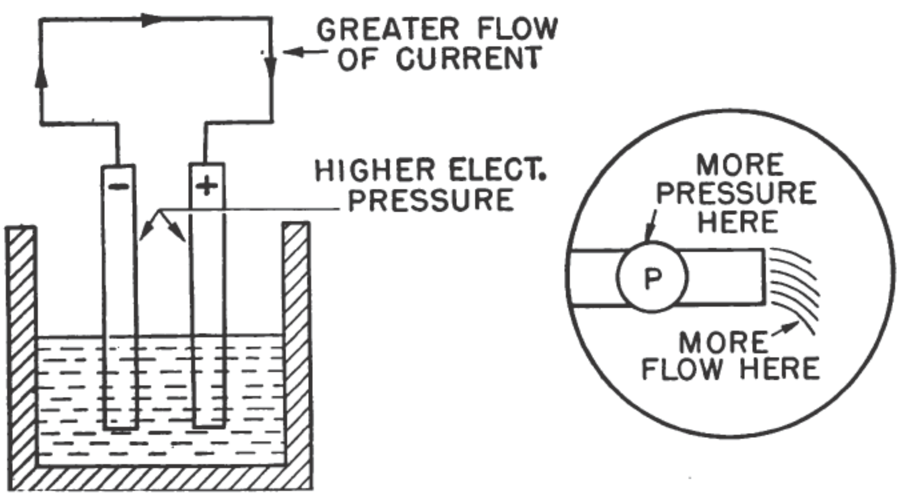


Figure 3.—Electrical circuits—increased electrical pressure—increased current flow.

Next there must be an "electrical pipe" to carry the flow. In the case of electricity, the pipes usually are solid pieces.

of metal and are called CONDUCTORS. The pipe in figure 2 plays the same part for water as the conductor does for electricity.

If you increase the pressure on the electrons in the conductor, a greater current will flow, just as an increased pressure on the water in a pipe will increase its flow (fig. 3).

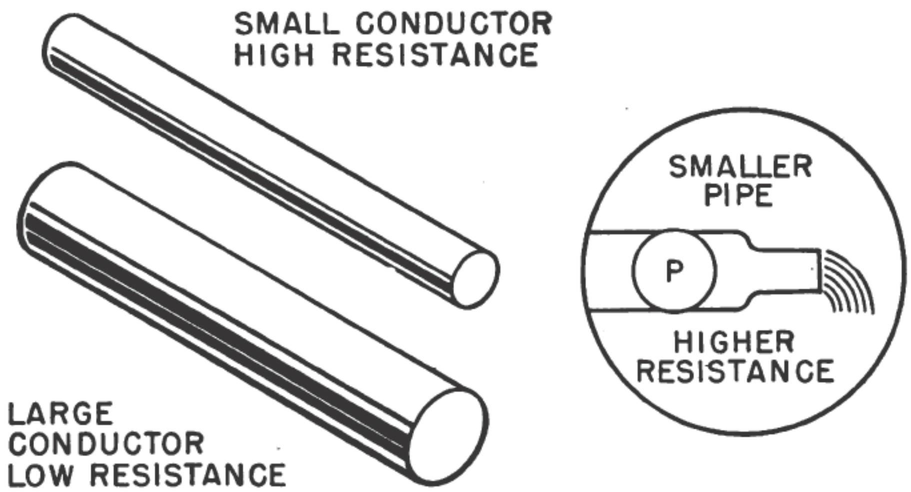


Figure 4.—Electrical circuits. Reduce the size of conductor—increase the resistance to current flow.

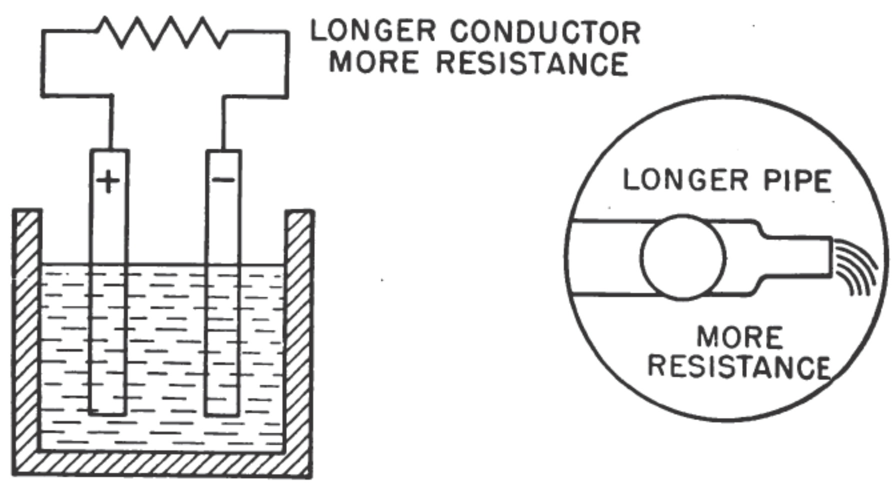


Figure 5.—Electrical circuits—the longer the conductor, the greater the resistance to current flow.

If the conductor is made smaller, figure 4, the electrical resistance is increased, just as a smaller pipe increases the resistance to the flow of water.

When a conductor is lengthened, the resistance is increased, just as a longer pipe increases the resistance to the flow of water (fig. 5). Each time you add another length of conductor in series, the resistance increases; hence it takes a greater electrical pressure to force the same amount of current through a long conductor than through a shorter one. You can see this comparison in figure 6. You must remember that the type of metal used in the conductor affects the resistance also. Since copper has a low resistance, it is used most frequently for ship and shore electrical systems.

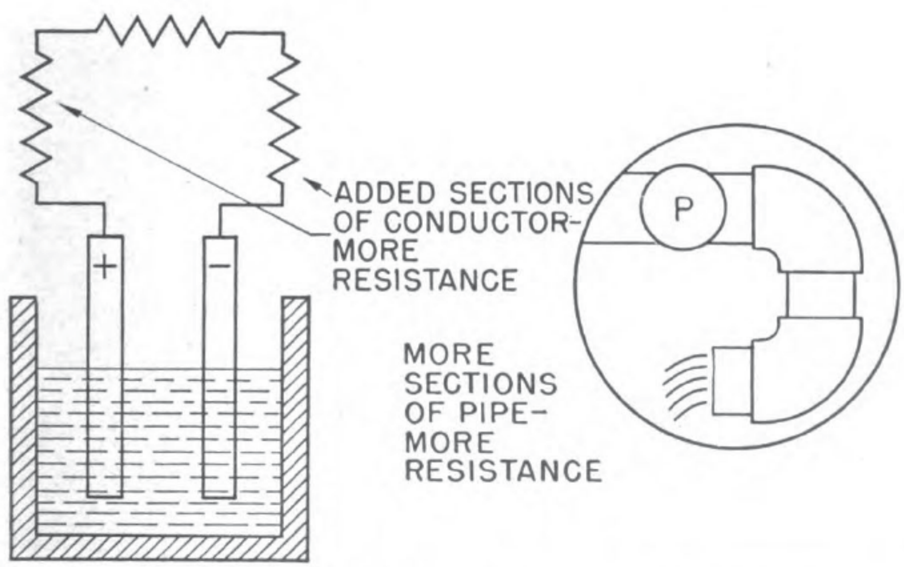


Figure 6.—Electrical circuits—adding resistances in series increases the total resistance to current flow.

It is obvious that no more water can flow out of a pipe than flows into it. All evidence points to the fact that the same is true of an electric current; no more current can leave a conductor than enters it. In practice this means that if you have a battery, generator, or any other source of electromotive force, just as much current returns to the source as flows away from it. This is known as KIRCHHOFF'S FIRST LAW.

Apply this law to a SERIES CIRCUIT, as illustrated in figure 7, and you see that THE CURRENT FLOWING IN ALL PARTS OF THE CIRCUIT IS IDENTICAL. If this law is applied to a

PARALLEL CIRCUIT, as shown in figure 21, you see that THE SUM OF ALL CURRENTS FLOWING TO A JUNCTION EQUALS THE SUM OF CURRENTS FLOWING AWAY FROM IT.

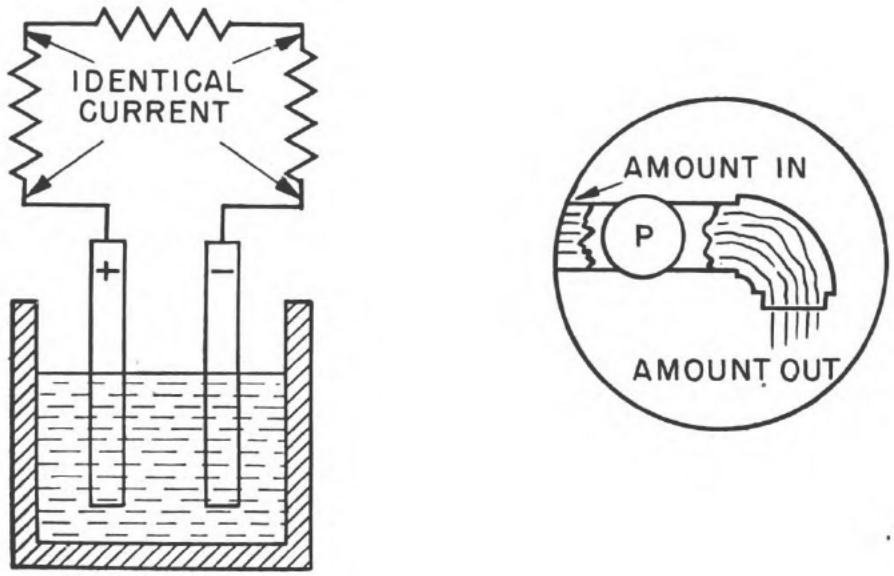


Figure 7.—Current in a series circuit is everywhere identical.

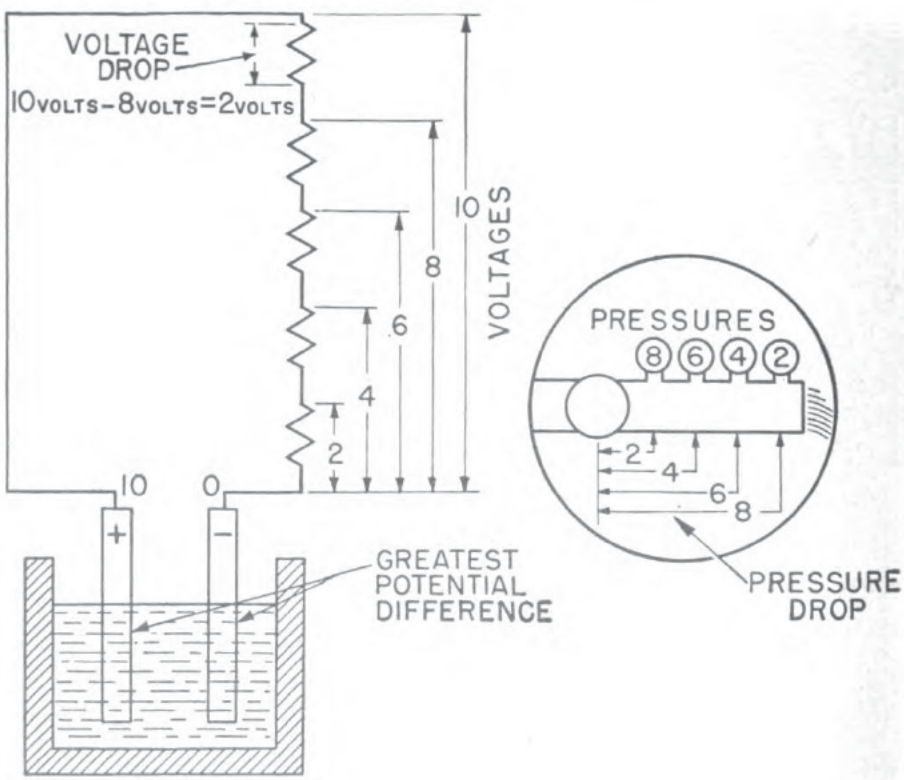


Figure 8.—Electrical pressure is greatest at its source.

Remember this law. You will use it hundreds of times in solving electrical problems. It is simple, but also very important.

Ever try to draw water from a tap near the end of a water main? Not much pressure? The pressure is always greatest at the pump and decreases with each step as you move away.

In electrical circuits, the pressure is the greatest at the source, or as in figure 8, at the positive terminal of the battery; the pressure decreases throughout the length of the circuit to zero pressure at the negative terminal. The difference in pressure between any two points in the circuit is the pressure drop, or potential difference. THE SUM OF ALL THE PRESSURE (VOLTAGE) DROPS IN A CIRCUIT IS EQUAL TO THE APPLIED ELECTROMOTIVE FORCE. This principle is known as KIRCHHOFF'S SECOND LAW. You will find many problems aboard ship concerning electrical pressure drops, so keep this law in mind.

THE THREE FACTORS—VOLT, OHM, AMPERE

All electrical circuits have the two factors of PRESSURE and RESISTANCE determining the third, CURRENT. Think of

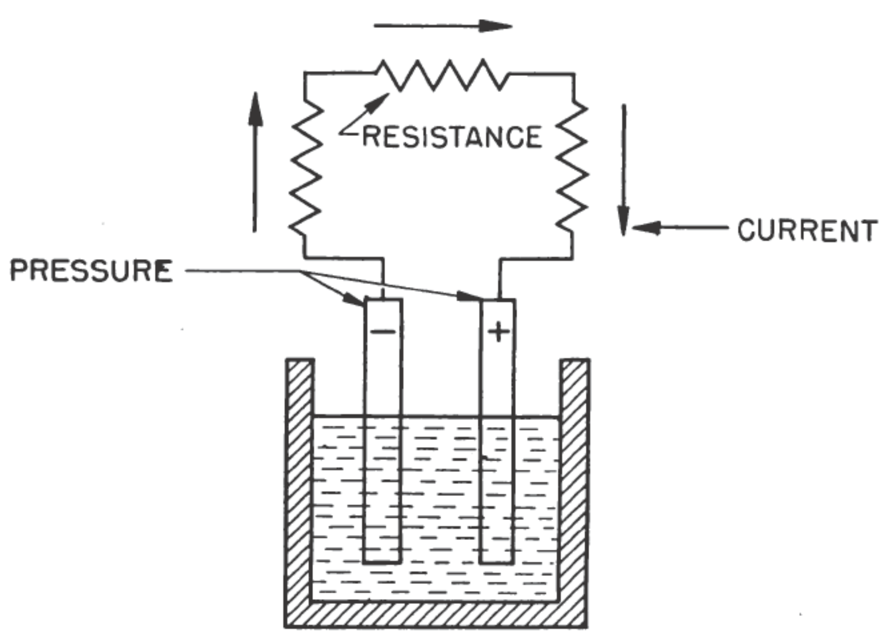


Figure 9.—The three factors in an electrical circuit.

these factors as illustrated in figure 9; pressure tends to move the electrons, and the resistance of the conductors tends to stop them.

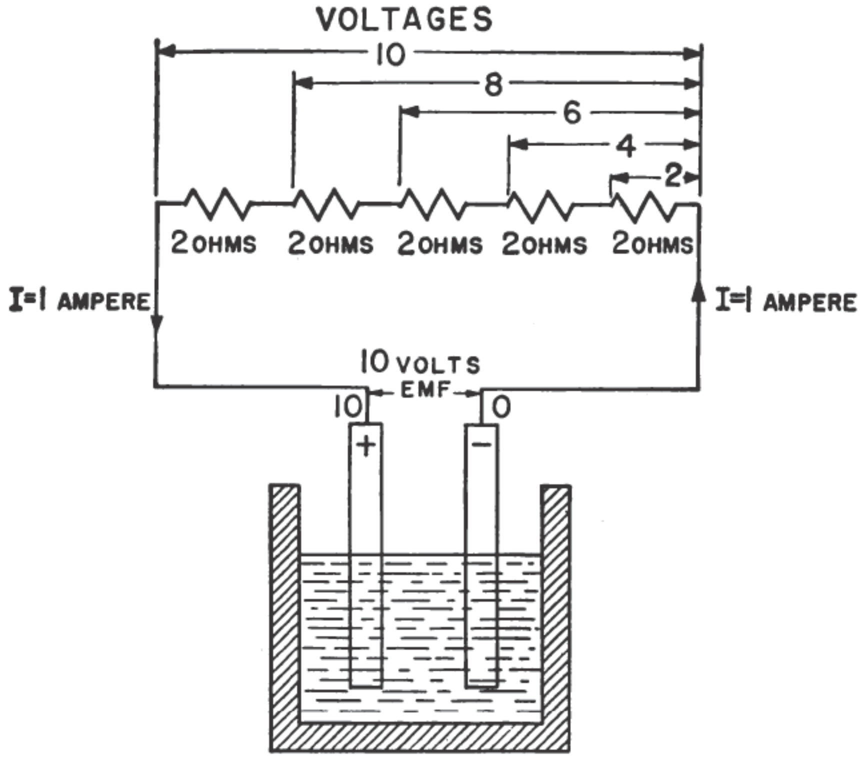


Figure 10.—Volts, ohms, and amperes in a circuit.

The term used to express the unit of electrical pressure is the VOLT. So whenever you see the terms VOLT or VOLTAGE used, remember it refers to the force or pressure tending to keep the electrons moving. Voltage is sometimes called ELECTROMOTIVE FORCE (emf). In most electrical formulas the symbol "E" is used to represent voltage.

The unit of resistance is the OHM, and like the volt it has an exact value. Briefly, it is the opposition to the flow of current offered by a column of mercury 106.300 centimeters long and weighing 14.4521 grams, when at 0° centigrade. In electrical equations the letter "R" is the symbol used to designate resistance.

The AMPERE expresses the number of electrons flowing past a point each second. Since the electron is extremely small, a bundle of 6.3 billion-billion electrons is used as unit and called a COULOMB. When a coulomb moves past a

point in a second, the amount of current flowing in the circuit is said to be one ampere.

Put the three factors—voltage, resistance, and current together as illustrated in figure 10, and you have the basis for all electrical computations. The current is determined by the applied voltage and the resistance offered by the circuit. Many times you will see this relationship stated as in

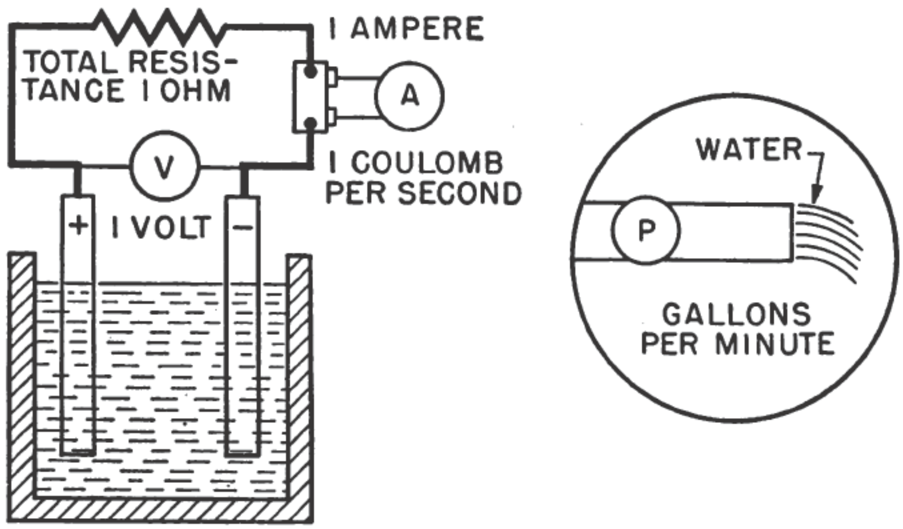


Figure 11.—One form of Ohm's law.

figure 11, where a current of 1 ampere will flow when the electrical pressure is 1 volt and the resistance of 1 ohm. It is just another way of stating OHM'S LAW.

MORE ABOUT OHM'S LAW

You learned in the preceding paragraphs that an increase in voltage means an increase in current, but an increase in resistance means a decrease in current. In other words the current flowing in a circuit is directly proportional to the applied voltage, and inversely proportional to the resistance. That is the most common way of stating Ohm's law. When you put this word statement into a mathematical relationship you get—

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}}$$

or $$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

or $$I = \frac{E}{R}$$

so if you know two of the values in Ohm's law, you can always find the third.

To aid in solving problems, Ohm's law can be written in two other forms. The first—

$$E = I \times R$$

enables you to find the voltage if you know the current and resistance.

The second form enables you to find the resistance of the circuit if you know the current and voltage. It is written—

$$R = \frac{E}{I}$$

Here are some practice problems.

1. What current will flow in a circuit containing a heater element with a resistance of 10 ohms when the applied voltage is 110?

Solution:

$$I = \frac{E}{R} \qquad I = \frac{110}{10} \qquad I = 11 \text{ amperes}$$

2. If you know a certain horn requires 6 amperes to operate it properly and the resistance of the circuit is 2 ohms, what is the required voltage?

Solution:

$$E = IR \qquad E = 6 \times 2 \qquad E = 12 \text{ volts.}$$

3. What resistance may a lamp requiring 3 amperes have, if only 6 volts are available to light it?

Solution:

$$R = \frac{E}{I} \qquad R = \frac{6}{3} \qquad R = 2 \text{ ohms}$$

In electrical circuits, resistance is indicated by a zigzag line. Turn back to figures 9, 10, or 11 and you will see this illustrated. Many times this symbol will indicate all forms of resistances whether they be coils, heating devices, or just the resistance of a conductor.

RESISTANCES IN SERIES

When you apply Ohm's law to circuits containing a single resistance, finding the current or voltage is a simple matter of substituting this single resistance value in the equations of Ohm's law, and then solving for the answer, as you did in the examples above. But if the circuit contains several resistances, you must find the combined resistance before the correct values of current and applied voltage can be found.

Resistances connected in a manner that provides only one path for the current to follow through the circuit and back

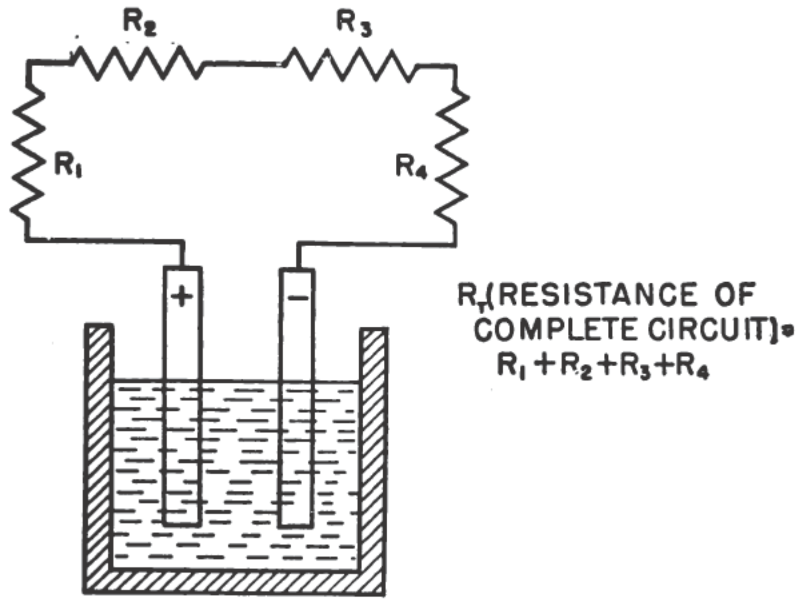


Figure 12.—Resistance of a series circuit.

to the source, are said to be connected in SERIES. The circuit in figure 12 is an example of a series connection. All current that flows through R_1 must flow through R_2, R_3 and R_4 before it returns to the source. Thus the total opposition to the flow of current will be the sum of all the individual resistances, or $R_T = R_1 + R_2 + R_3 + R_4$.

The devices connected in a series circuit are linked together by conductors and connections. These also have resistance, and their resistances must be added to the resistance of the devices connected in the circuit to get the total resistance of a series circuit. Since the resistance of the conductor depends on its length, size, and the material it is made of,

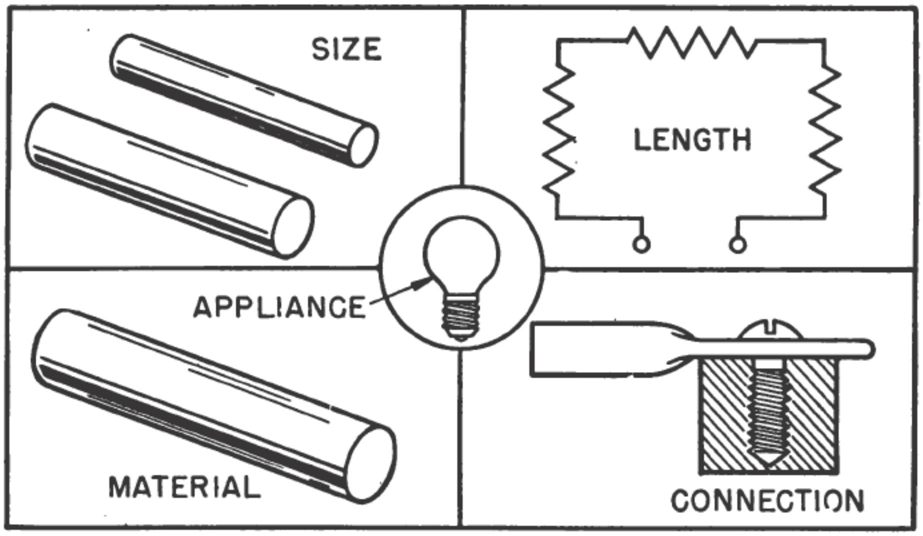


Figure 13.—Factors that determine the resistance of a circuit.

the total resistance of a series circuit is determined by the factors illustrated in figure 13.

It is important to remember about this extra resistance due to conductors and connections, because in low resistance circuits (battery circuits, firing circuits, etc.) the greatest part of the circuit resistance is due to the conductors and connections used.

VOLTAGE DROPS IN A SERIES CIRCUIT

Figure 14 is an illustration of three lamps in series, and if the lamps are considered to be the only resistances in the circuit the total resistance of the circuit will be—

$$R_T = R_1 + R_2 + R_3$$

and the current will be—

$$I_T = I_1 = I_2 = I_3$$

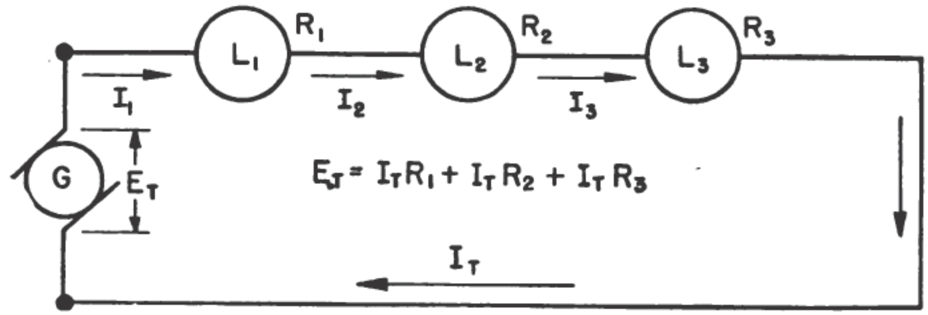


Figure 14.—Voltage in a series circuit.

The combined voltage drop across the lamps will be the sum of the individual voltage drops—

$$I_TR_T=I_1R_1+I_2R_2+I_3R_3$$

But in a series circuit the current is everywhere equal, so I_1, I_2, and I_3 are the same as I_T, and the combined voltage drop across the lamps will be—

$$I_TR_T=I_TR_1+I_TR_2+I_TR_3$$

or,

$$I_TR_T=I_T\ (R_1+R_2+R_3)$$

Since in this circuit the lamps are considered to contain all the resistances, the total voltage drop of the circuit must be equal to the total applied voltage—

$$E_T=I_T\ (R_1+R_2+R_3)$$

Thus you may say, THE SUM OF THE INDIVIDUAL IR DROPS ABOUT A SERIES CIRCUIT IS EQUAL TO THE APPLIED VOLTAGE.

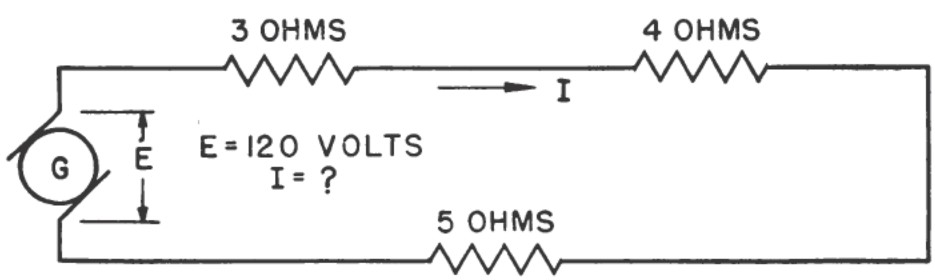


Figure 15.—A series circuit problem.

Here are two sample problems of resistors in series. More may be found in the problems for this chapter given in the QUIZ at the end of this chapter.

1. The generator in figure 15 produces an emf of 120 volts, and the circuit contains resistors of 3, 4, and 5 ohms. What is the current?

First find the total resistance—

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 3 + 4 + 5$$

$$R_T = 12 \text{ ohms}$$

Now substitute the values of E and R_T in the formula for Ohm's law—

$$I = \frac{E}{R} \qquad I = \frac{120}{12} \qquad I = 10 \text{ amperes.}$$

2. The series circuit illustrated in figure 16 is carrying 6 amperes of current and contains 3 lamps of 2, 4, and 6 ohms. What is the applied voltage? What is the *IR* drop across each lamp?

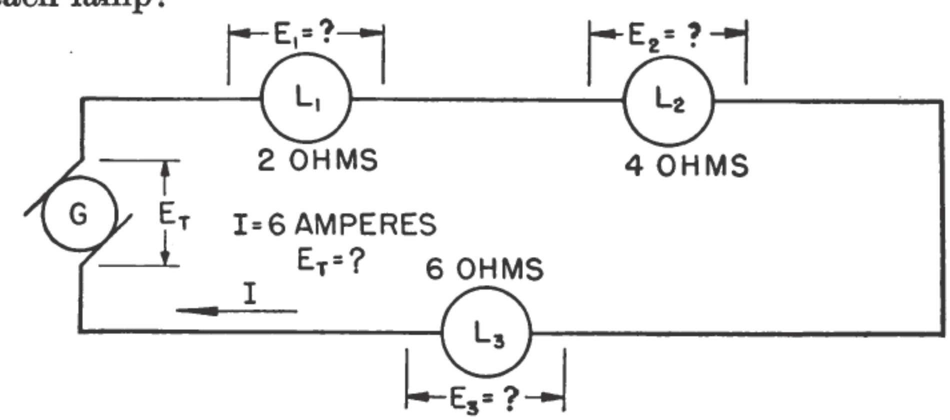


Figure 16.—Another series circuit problem.

First find the total resistance—

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 2 + 4 + 6$$

$$R_T = 12 \text{ ohms}$$

Using the equation $E_T = IR_T$ and substituting the correct values of I and R_T—

$$E_T = 6 \times 12$$

$$E_T = 72 \text{ volts}$$

Since each lamp is carrying 6 amperes, the individual IR drops will be—

For L_1—$E_1 = 6 \times 2 = 12$ volts.

For L_2—$E_2 = 6 \times 4 = 24$ volts.

For L_3—$E_3 = 6 \times 6 = 36$ volts.

RESISTANCES IN PARALLEL

In parallel circuits, the appliances are connected in such a manner that the total circuit current is divided between them. Each appliance then provides a branch path for the current to follow. Look at figure 17. The lamps form three branch

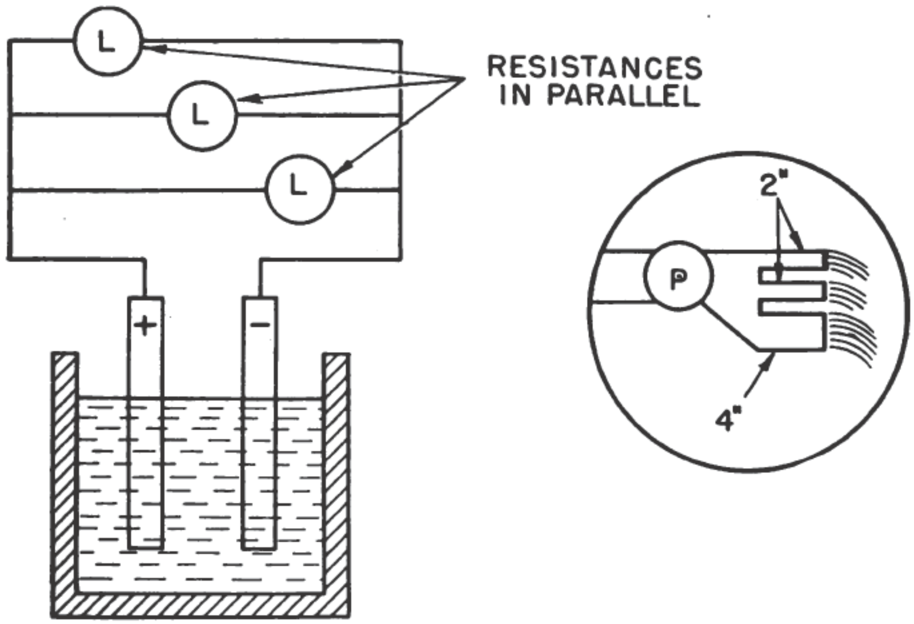


Figure 17.—Parallel circuit.

paths for the current. Naturally the total resistance is less than what it would be if only one of the lamps were present.

You may think of the lamps in parallel as a water pipe

having three outlets. When the outlets are all the same size, the total resistance offered will be—

$$\text{Total resistance} = \frac{\text{Resistance of one outlet}}{\text{Number of outlets}}$$

or, if the three lamps in figure 17 are of the same resistance, the total resistance will be—

$$R_T = \frac{\text{Resistance of one lamp}}{3}$$

So if each lamp has a resistance of 12 ohms, the total resistance will be—

$$R_T = \frac{12}{3} = 4 \text{ ohms.}$$

UNEQUAL RESISTANCES IN PARALLEL

Seldom will you find parallel circuits that contain resistances all of equal value. The task of finding the total resistance is then a little more complicated. In this case the simplest way to find the total resistance is to use the formula—

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

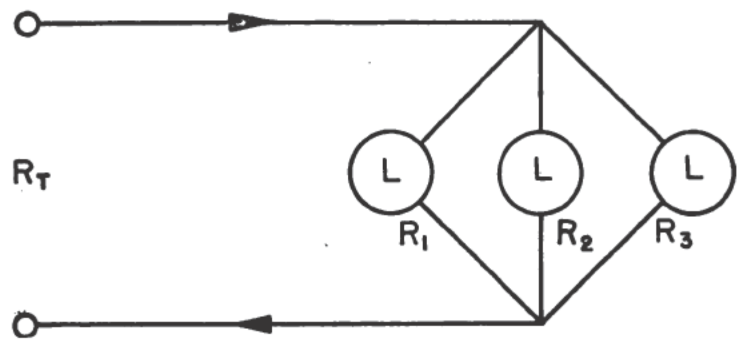


Figure 18.—Resistance in parallel.

Now try a problem to see how this system works out. In figure 19 you have three resistances (30, 50, and 75 ohms) in parallel, and you wish to know the total current when the applied voltage is 120.

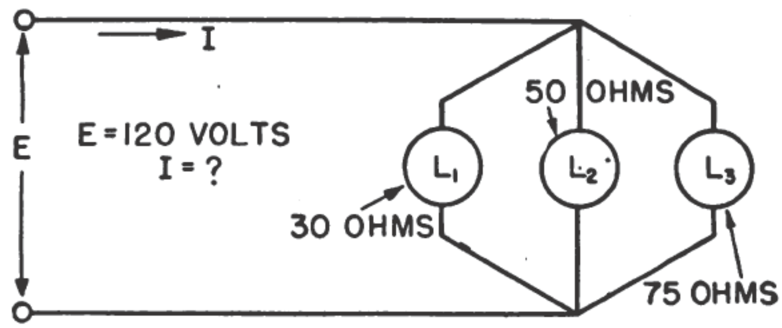


Figure 19.—A problem on resistances in parallel.

First find the total resistance using the formula

$$\frac{1}{R_T}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$$

Substitute the values of resistance for R_1, R_2, and R_3—

$$\frac{1}{R_T}=\frac{1}{30}+\frac{1}{50}+\frac{1}{75}$$

Next find the least common denominator and add

$$\frac{1}{R_T}=\frac{5+3+2}{150}$$

$$\frac{1}{R_T}=\frac{10}{150}$$

To find R_T, cross multiply and solve—

$$10R_T=150$$

$$R_T=15 \text{ ohms.}$$

Now you find the current from Ohm's law. Since E is 120 volts—

$$I=\frac{E}{R} \qquad I=\frac{120}{15} \qquad I=8 \text{ amperes}$$

VOLTAGES IN PARALLEL CIRCUITS

In parallel circuits, the voltage across each branch of the circuit is equal to the voltage across every other branch.

Thus, in figure 20, the voltages across L_1, L_2, and L_3 are all the same and are equal to the applied voltage; that is—

$$E = E_1 = E_2 = E_3$$

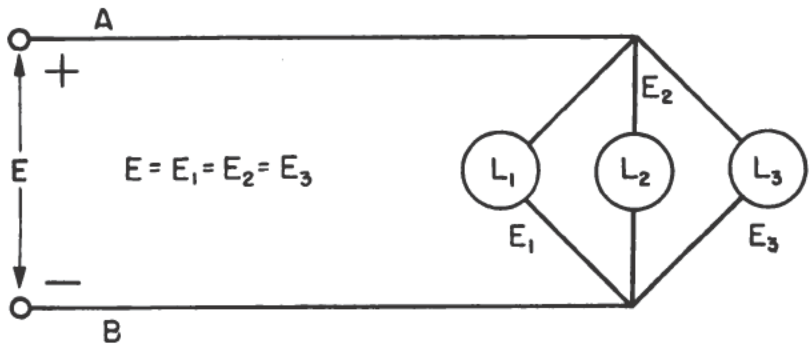


Figure 20.—Voltages in parallel circuits.

This principle holds regardless of the number of branches, or the relative resistance of each. The VOLTAGES ACROSS ALL LEGS OF A PARALLEL CIRCUIT ARE EQUAL.

CURRENT IN PARALLEL CIRCUITS

Since the voltages across all parallel branches of a circuit are equal, the most current, like most water, will flow through the branch of lowest resistance. Turn back to figure 17 again. The resistance of the 4-inch outlet is less than that of the 2-inch, so more water will flow through it. The same thing is true in electrical circuits; the most current flows through the lowest resistance.

In figure 19 you have three unequal resistances; 30, 50, and 75 ohms. Naturally the most current will flow through the 30-ohm lamp, and the least through the 75-ohm lamp, but how much through each? The solution to the problem is just one of applying Ohm's law to each leg of the circuit. The voltage applied to the lamp in each leg is 120, since the voltages across all parallel branches of a circuit are equal.

Here is the solution

The current through L_1 is—

$$I_1 = \frac{120}{30} = 4.0 \text{ amperes}$$

The current through L_2 is—

$$I_2 = \frac{120}{50} = 2.4 \text{ amperes}$$

The current through L_3 is—

$$I_3 = \frac{120}{75} = 1.6 \text{ amperes}$$

How about the total current? You read in a preceding paragraph Kirchhoff's FIRST LAW, which says that AS MUCH CURRENT FLOWS AWAY FROM A POINT AS FLOWS INTO IT.

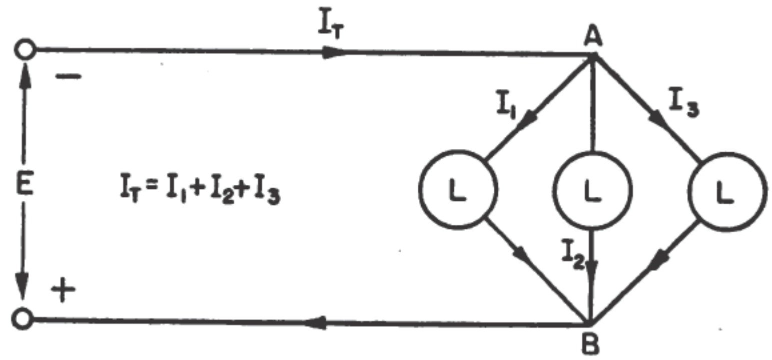


Figure 21.—Currents in a parallel circuit.

Thus, as shown in figure 21, at point A the total current must divide and flow through the three lamps, and at point B the three currents from the lamps must all unite to form the total current, which flows back to the battery. In other words, THE TOTAL CURRENT MUST BE THE SUM OF THE INDIVIDUAL CURRENTS, or—

$$I_T = I_1 + I_2 + I_3$$

$$I_T = 4.0 + 2.4 + 1.6$$

$$I_T = 8 \text{ amperes.}$$

SAMPLE PROBLEM—PARALLEL CIRCUITS

Figure 22 is a sample problem of resistances in parallel. You are asked to find the resistance of L_3.

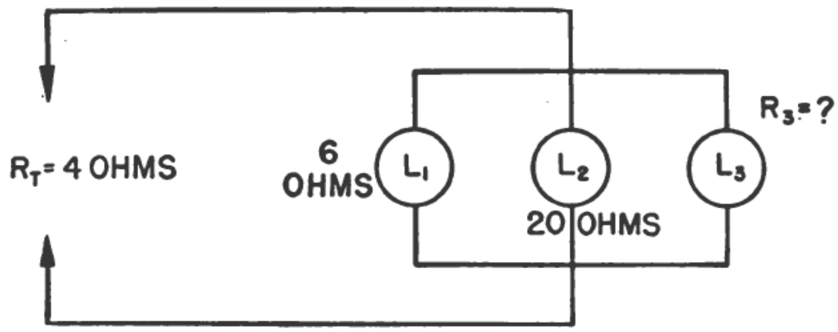


Figure 22.—Sample problem on resistances in parallel.

First substitute the known values of resistance in—

$$\frac{1}{R_T}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$$

$$\frac{1}{4}=\frac{1}{6}+\frac{1}{20}+\frac{1}{R_3}$$

Then solve for R_3—

$$\frac{1}{4}-\frac{1}{6}-\frac{1}{20}=\frac{1}{R_3}$$

$$\frac{15-10-3}{60}=\frac{1}{R_3}$$

$$\frac{2}{60}=\frac{1}{R_3}$$

$$2R_3=60$$

$$R_3=30 \text{ ohms}$$

In the preceding problem you used the same parallel resistance formula. The only difference between this and other examples is the unknown you solved for.

You may have problems with 4, 5, 6 and even many more resistances in parallel. In that case, the parallel resistance formula just gets longer, such as—

$$\frac{1}{R_T}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\frac{1}{R_4}+\frac{1}{R_5}---$$

for as many more as you wish to add.

More practice problems on parallel circuits can be found in the questions for this chapter in the QUIZ at the end of this chapter. Try your luck.

SERIES-PARALLEL CIRCUITS

Many hook-ups of resistances in combinations of series and parallel circuits will be found aboard ship. No new formulas need be used. You just break the complete circuit into simple series and parallel circuits. Solve each part separately and then combine the parts.

Here is a sample problem. In figure 23A five resistances are connected as indicated. You are asked to find the total current.

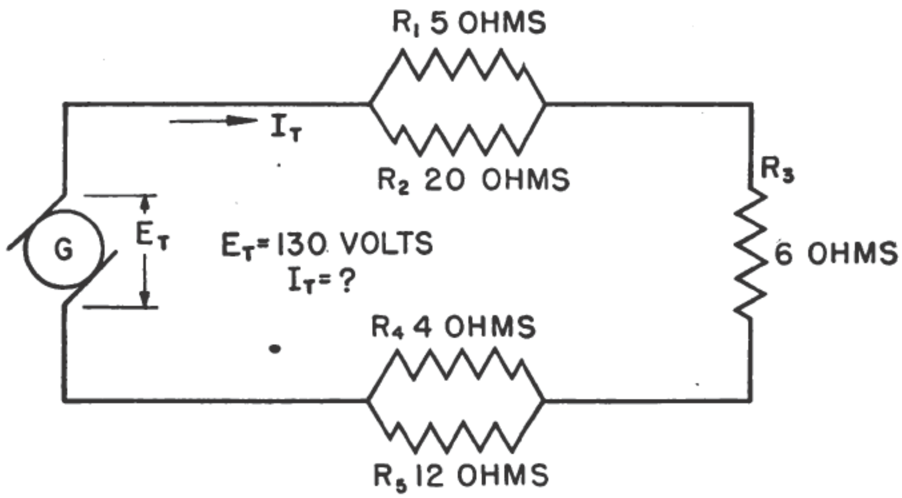


Figure 23A—A series-parallel circuit.

The first step is to find the combined resistance of R_1-R_2 and R_4-R_5, by using the parallel resistance formula for each group.

For group R_1-R_2, the equivalent resistance, R_x, is—

$$\frac{1}{R_X}=\frac{1}{5}+\frac{1}{20}$$

$$\frac{1}{R_X}=\frac{4+1}{20}$$

$$\frac{1}{R_X}=\frac{5}{20}$$

$$R_X=4 \text{ ohms.}$$

For group R_4-R_5, the equivalent resistance, R_y, is—

$$\frac{1}{R_y}=\frac{1}{4}+\frac{1}{12}$$

$$\frac{1}{R_y}=\frac{3+1}{12}$$

$$\frac{1}{R_y}=\frac{4}{12}$$

$$R_y=3 \text{ ohms}$$

The combined resistance of R_1-R_2 is 4 ohms, and of R_4-R_5, 3 ohms. As far as the flow of current is concerned, a single resistance of 4 ohms can replace R_1-R_2, and one of 3 ohms can replace R_4-R_5. Thus for calculation it is possible to redraw the circuit as in figure 23B and get a cir-

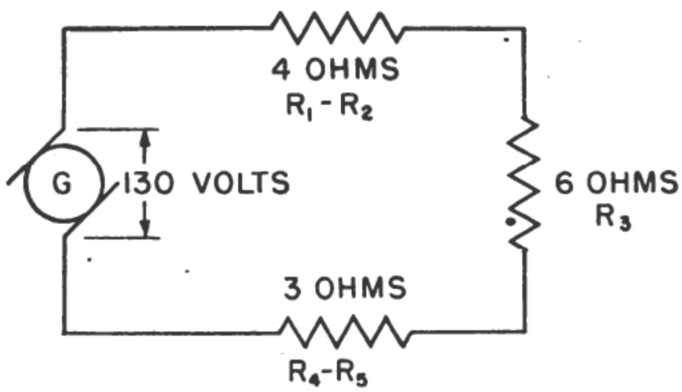


Figure 23B.—Equivalent circuit of figure 23A.

cuit with three resistances of 4, 6, and 3 ohms in series. The total resistance will be—

$$R_T=4+6+3=13 \text{ ohms}$$

and the current will be—

$$I=\frac{E}{R}$$

$$I=\frac{130}{13}$$

$$I=10 \text{ amperes}$$

Figure 24A presents another example of a series-parallel problem. It has a few more resistors than the preceding problem, but it is just as simple. You are told that the current in the circuit, I, produces an IR-drop across the 2-ohm resistor of 24 volts. What voltage must the generator have?

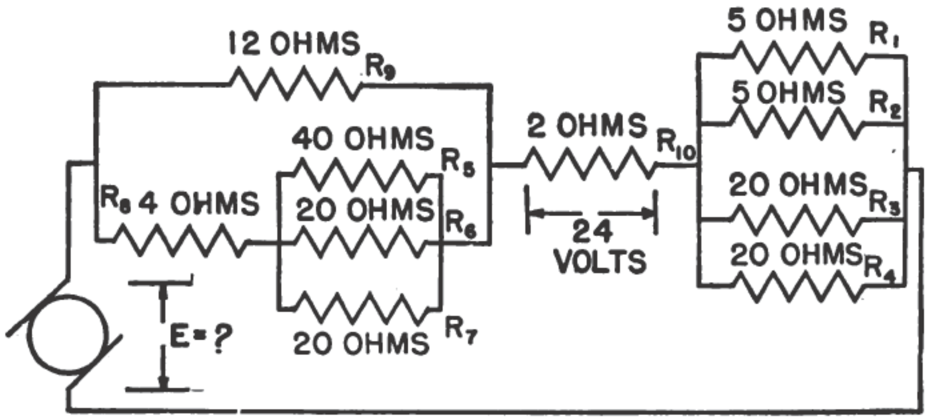


Figure 24A.—A series-parallel network.

The first step is to find R_X, the combined resistance of the R_1, R_2, R_3, R_4 branch. Using the parallel resistance formula—

$$\frac{1}{R_x}=\frac{1}{5}+\frac{1}{5}+\frac{1}{20}+\frac{1}{20}$$

$$\frac{1}{R_x}=\frac{10}{20}$$

$$R_x=2 \text{ ohms}$$

Now for the R_5, R_6, R_7 branch, R_y—

$$\frac{1}{R_y}=\frac{1}{40}+\frac{1}{20}+\frac{1}{20}$$

$$\frac{1}{R_y}=\frac{5}{40}$$

$$R_y=8 \text{ ohms}$$

Look at figure 24B. A single resistor R_x of 2 ohms is equivalent to and replaces the R_1, R_2, R_3, R_4 parallel circuit; while R_y of 8 ohms replaces R_5, R_6, R_7.

Combine R_8 and R_y (4+8) and you have 12 ohms in parallel with resistance R_9, also of 12 ohms. So R_z, the effective resistance of this parallel circuit, is—

$$\frac{1}{R_z}=\frac{1}{12}+\frac{1}{12}$$

$$R_z=6 \text{ ohms}$$

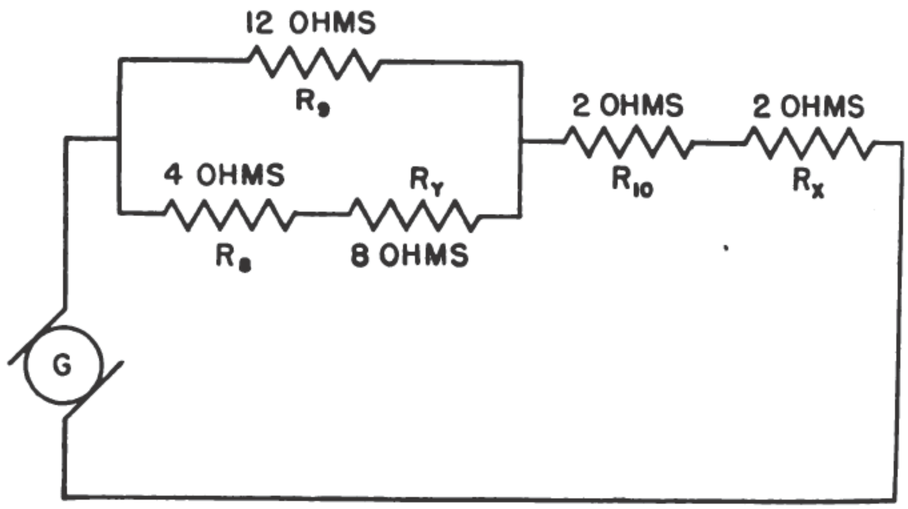


Figure 24B.—Equivalent circuit of figure 24A.

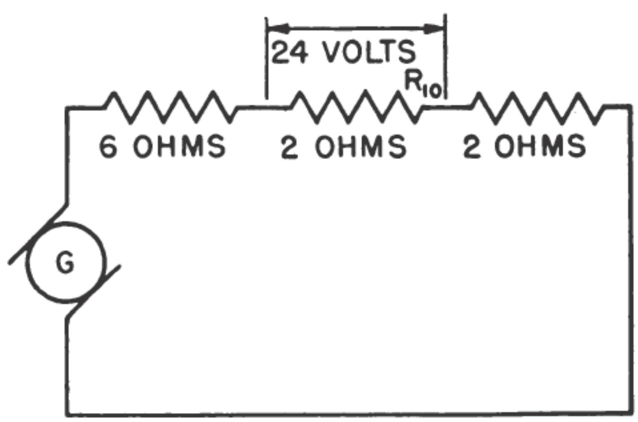


Figure 24C.—Most simplified form of circuit of figure 24A.

Now you have resolved your series-parallel circuit into an equivalent circuit with three resistors in series, as shown in figure 24c. Thus the total resistance of the circuit will be—

$$R_T=6+2+2$$

$$R_T=10 \text{ ohms.}$$

Look back at figure 24A again. A 24-volt IR drop is indicated across the 2-ohm resistor. You know the resistance is 2 ohms and the voltage 24, so by using Ohm's law the current is found to be—

$$I=\frac{24}{2}=12 \text{ amperes}$$

Since in figure 24A, R_{10} is in series with the rest of the circuit, 12 amperes must be the total being delivered by the generator. In that case, the IR drop across the 6-ohm resistor and the other 2-ohm resistor will be

$$E_1=6 \times 12$$

$$E_1=72 \text{ volts.}$$

$$E_2=2 \times 12$$

$$E_2=24 \text{ volts.}$$

The total IR drop across the whole circuit is—

$$E=72+24+24$$
$$E=120 \text{ volts.}$$

And 120 volts is the emf being delivered by the generator.

POWER IN ELECTRICAL CIRCUITS

You learned in *Basic Electricity* that power is the RATE of doing work, and that electrically, power is equal to the product of the current times the voltage, or—

$$P=E\times I$$

Like water flowing out of a pipe, the greater the volume and greater the pressure, the larger will be the power.

Look back again at the problem you just completed. The current was 12 amperes, with an applied E of 120 volts, so the power of the circuit is

$$P=120\times 12$$

$$P=1440 \text{ watts.}$$

More problems dealing with power in series and parallel circuits are found in the QUIZ at the end of the chapter. The more you practice, the better you will be able to solve these problems.

HEATING IN ELECTRICAL CIRCUITS

You know from Ohm's law that $E=IR$, so you can substitute IR for E in the power equation of the preceding paragraph and from $P=E\times I$ you get

$$P=IR\times I$$

$$P=I^2R$$

This means that the POWER, or the electrical energy used up each second, in forcing electrons through a conductor depends on the RESISTANCE of the conductor and the SQUARE OF the CURRENT.

This power is the electrical energy used up, each second, in forcing a current I through a conductor whose resistance is R. The electrical energy thus "used up" does not disappear; it is merely transformed into heat which warms the conductor. Therefore every electrical machine or piece of electrical equipment that has conductors—a motor, generator, transformer, or even a cable—is heated by the current going through it. The above formula tells us how much heating the current produces.

Consider an example: A motor which has an armature resistance of 1 ohm, when operating at full load had an armature current of 5 amperes. Therefore the power used up in heating the armature is—

$$P=I^2R \qquad P=5\times5\times1 \qquad P=25 \text{ watts}$$

Now suppose the motor is overloaded so that the armature current goes up to 10 amperes. Then—

$$P=I^2R \qquad P=10\times10\times1 \qquad P=100 \text{ watts}$$

This shows you what it means when you say "the power used up in heating a conductor goes up as the square of the

current in the conductor." It means that a small increase in current produces a great increase in heating. Thus in the problem above, when the current was only DOUBLED the heating increased FOURFOLD. For this reason it is dangerous to overload electrical machines, because even a slight overloading produces a great increase in heating. Often this increased heating will char or break down the insulation around the conductor, and this leads to grounds, shorts, etc., and soon the machine is ruined. In short, OVERLOADING of electrical machines MEANS OVERHEATING, and overheating starts a destructive process which will rapidly ruin the machine. So—when operating electrical machinery always be careful—DO NOT OVERLOAD.

To help you tell when machines are being overloaded each electrical machine bears a name plate which tells you how much current the machine takes at full load, and how much it is heated up (what temperature rise it has) at this current. The temperature rise is usually given as so many degrees rise "above ambient temperature". The AMBIENT here means the temperature of the compartment in which the machine is located.

QUIZ

1. The unit of electrical pressure is the ------.
2. The unit of electrical current is the ------.
3. The unit of electrical resistance is the ------.
4. The current in a circuit is
   (a) ------ proportional to the applied voltage.
   (b) ------ proportional to the resistance.
5. The relation between current, voltage and resistance in a circuit is expressed by the equation
   Amperes=------.
6. If a generator supplies 60 volts across a resistor and a current of 10 amperes flows through the circuit, what is the ohmic value of the resistor?
7. A generator is supplying 120 volts to a circuit which

comprises two resistances, 6 ohms and 4 ohms, in series. What is the current flowing in the circuit?

8. What voltage must a generator have to produce a current of 6 amperes through resistances of 2 ohms, 3 ohms, and 5 ohms connected in series?
9. Four resitors, of 8 ohms, 6 ohms, 2 ohms and one of unknown resistance, are connected in series. A generator supplies 120 volts across this circuit. The IR-drop across the 6-ohm resistance is 36 volts. (a) What current is flowing in the circuit? (b) What is the total circuit resistance? (c) What ohmic value has the unknown resistor?
10. A generator supplies 100 volts to 3 resistors in series, whose resistances are 2 ohms, 3 ohms and 5 ohms. (a) What current flows in the circuit? (b) What is the current in each resistor?
11. Find the current that would flow in a circuit of 6 ohms and 8 ohms connected in series, if 140 volts were impressed on the circuit.
12. A generator furnishes 100 volts to a group of 3 resistors connected in parallel. One resistor is 7 ohms, another 2 ohms, and the third 1 ohm. (a) What current flows in each resistor? (b) What is the total current flowing in the circuit? (c) What is the equivalent resistance of all 3 resistors in parallel?
13. A current of 10 amperes flows in a circuit containing 2 resistances in parallel, one 12 ohms and the other 6 ohms. What is the voltage impressed on the circuit?
14. A generator is supplying 10 amperes to a 5-ohm resistor and an unknown resistor in parallel. If 8 amperes flows through the 5-ohm resistor, what is the ohmic value of the unknown resistor?
15. Four resistors are connected in parallel. One is 12 ohms, one is 4 ohms, and the other two are unknown. The current through one unknown resistor is 12 amperes and through the other unknown 20 amperes when this combination is put across a 120-volt generator. (a) What is the total current the generator supplies to the circuit? (b) What is the total power consumed in the circuit? (c) How much power is used up in each resistor?

16. A generator suppiies 150 volts to 3 resistances in parallel. One resistor is 50 ohms, one 75 ohms, and the third is unknown. (a) If 5 amperes flows through the unknown resistor, what is its resistance? (b) How much power is expended in each resistor? ? (c) How much power is taken by the whole circuit?

17. A generator expends 2,880 watts when supplying a current of 12 amperes to a circuit consisting of 3 resistances in parallel. One is 60 ohms, another 40 ohms, and the third unknown. What is the ohmic value of the unknown resistance?

18. A 35-ohm resistor is in series with a parallel group which contains a 50-ohm resistor, a 30-ohm resistor and an unknown resistor. If the total resistance of the circuit is 50 ohms, what is the ohmic value of the unknown resistor?

19. An unknown resistor is placed in series with two other resistances connected in parallel. One is 5 ohms, the other one is 20 ohms. This combination of three resistances is in parallel with one of 50 ohms. If 120 volts is impressed on the circuit and 10 amperes flows, what is the ohmic value of the unknown resistor?

20. Three groups of resistances are connected in series. The first group contains 20 ohms and 30 ohms in parallel. The second group contains 6 ohms and an unknown in parallel. The third group contains 40 ohms and 60 ohms in parallel. If 120 volts is impressed on the circuit and 3 amperes flow, what is the ohmic value of the unknown resistor?

21. What voltage must a generator have in order to force 20 amperes through a 2-ohm resistor in series with a parallel group of two others having resistances of 3 ohms and 6 ohms?

22. How much power is expended by a generator that furnishes 130 volts to the following three groups of resistances connected in series? The first group contains 5 ohms and 20 ohms in parallel. The second group contains a 6-ohm resistor. The third group contains 4 ohms and 12 ohms in parallel.

23. A generator supplies 120 volts to a lighting circuit. A group of lamps connected in parallel across the line, nearest the generator, contains two lamps in parallel. A second group also across the line contains three lamps in parallel. The resistance of each side of the line from the generator to the first group of lamps is 0.4 ohm. The resistance of each side of the line between the first group of lamps and the second group is 0.5 ohm. Find the voltage across each group of lamps if each lamp draws 1 ampere.

24. Fill in the blanks below with the appropriate word to make each sentence a true statement.

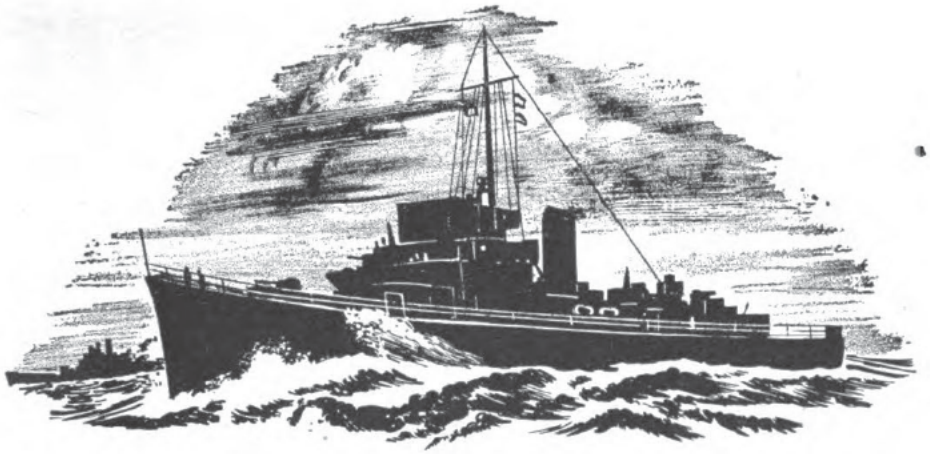
    (a) The electrical energy used up in forcing a current through a conductor is transformed into ------.

    (b) The electrical energy used up each second in forcing electrons through a conductor depends on the ------ of the conductor.

    (c) The electrical energy used up each second in forcing electrons through a conductor depends on the square of the ------.

    (d) A slight overload will produce a ------ increase in heating.

25. How does overheating of a conductor affect the insulation around it?



CHAPTER 2
MAGNETISM
IMPORTANCE OF MAGNETISM

Magnetism is so common and many of its characteristics have been known by every boy for so many years that its real importance in the electrical world is apt to be overlooked. Magnets and magnetism are involved vitally in the operation of nearly all electrical machinery. Without it there would not be any motors, telephones, radios, telegraphs, and hundreds of other common items. In fact, electricity would still be an infant of no particular value to anyone instead of a powerful giant, if the use of magnetism to generate electricity had not been discovered.

Since magnetism plays such an important role in electricity, a good review of what you have learned in the *Basic Electricity* text added to your own practical experience will insure that you are off on the right track.

NATURAL MAGNETS

Many different stories are told of how magnetism was discovered, but all relate how ancient shepherds of Magnesia, a section of Asia Minor, found a stone that had the ability to attract the iron tips of their staffs. Naturally the full

meaning of this phenomenon was not understood, but little by little the ancient shepherds, then sailors, and later scientists, assembled the important characteristics of magnetism.

The strange rock proved to be a piece of the iron ore now called MAGNETITE. Because of its tendency to attract iron objects, and because it always tends to assume a north-south direction, it was given the name LEADING STONE, later shortened to the name LODESTONE.

The lodestone had obtained its magnetism from the magnetic field of the earth. The stone had spots where the magnetism seemed to concentrate like the earth's north and south magnetic poles, so the lodestone also was said to have magnetic poles.

Lodestones are considered NATURAL magnets. They are not powerful in their ability to attract iron objects, so are seldom used in any electrical machinery. Their chief use is for demonstration and to produce ARTIFICIAL magnets of iron and steel.

MAGNETIC MATERIALS

Iron, and its derivative steel, make the strongest artificial magnets. Several other metals—nickel, cobalt, magnesium, cerium, and chromium—also possess magnetic properties but these are weaker than in iron. Recently, alloys formed of the magnetic materials and some nonmagnetic substances such as aluminum have shown magnetic properties of far greater strength than iron or steel. Alnico is one of these alloys. Other examples are permalloy, perminvar, and hipernick.

NONMAGNETIC MATERIALS

Any material not attracted by a magnet is considered nonmagnetic. This includes practically all materials except those mentioned in the preceding paragraph. Air, copper, aluminum, rubber, wood, fiber, and bakelite are a few of the nonmagnetic materials with which an electrician's mate is familiar.

You should not confuse nonmagnetic materials with nonconductors of electricity. While nonmagnetic substances are not affected by magnetism, they are TRANSPARENT to mag-

netic forces. You cannot insulate magnetism as you do electricity. A magnet will attract iron filings through air, paper, wood, or glass.

ARTIFICIAL MAGNETS, PERMANENT AND TEMPORARY

When a bar of hardened steel is stroked along its length in a single direction by one end of a lodestone, the bar acquires magnetic properties similar to those of the lodestone. Magnets formed in this manner are artificial magnets. If a bar of soft iron is placed end-to-end with the hard steel, artificial magnetism will be INDUCED in it. The soft iron bar will also be an artificial magnet, but if the soft iron bar is taken away from the hard steel bar the soft iron bar quickly loses its magnetism, while the hard steel retains its magnetic powers. The hard steel forms a PERMANENT magnet, while the soft iron is a TEMPORARY magnet.

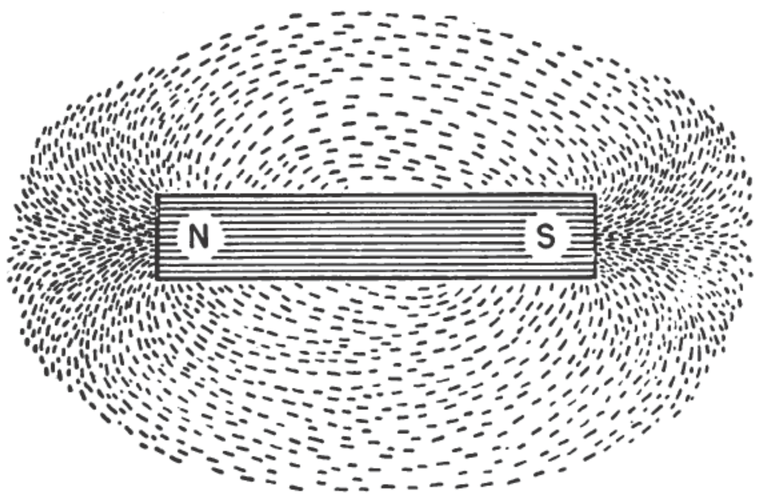


Figure 25.—Magnetic field about a magnet.

Artificial magnets, made of hard steel and certain alloys, are much more powerful than natural magnets, which are relatively weak. The natural magnets have no practical use in any practical electrical machinery. Artificial magnets may be made in various shapes, such as a straight bar, horseshoe or U-shaped.

MAGNETIC FIELD ABOUT A BAR MAGNET

Iron filings sprinkled on a thin sheet of cardboard placed over a bar magnet will arrange themselves in curved lines

about the magnet as in figure 25. The arrangement of the filings will be more pronounced if the cardboard is tapped gently as the filings are sprinkled.

Magnetism shows itself as if "lines" existed from one pole to the other, as seen in figure 26. These lines are called LINES OF MAGNETISM or MAGNETIC LINES OF FORCE. The

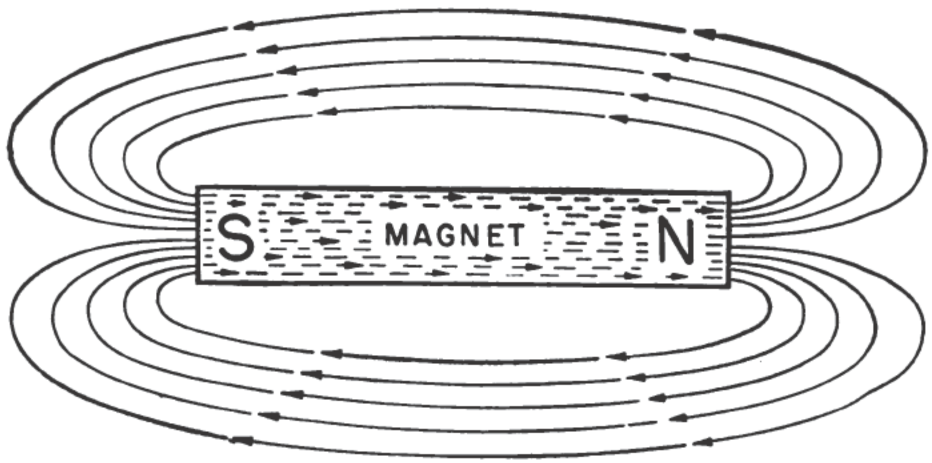


Figure 26.—Magnetic lines.

whole arrangement usually is called the MAGNETIC FLUX. The space occupied by these lines is called the MAGNETIC FIELD. The path through which magnetic lines pass is called the MAGNETIC CIRCUIT.

Exploring the field about a bar magnet with a magnetic compass will show the field to exist all about the magnet. It is probable that if the lines of magnetism were visible, they would completely hide all parts of the magnet from view.

MAGNETIC FIELD STRENGTH

The number of lines of force in the cross-section area of a magnetic field describes the STRENGTH of the magnet. This strength is often referred to as FLUX DENSITY and is expressed in so many thousand LINES PER SQUARE INCH of cross section. The unit of flux density is the GAUSS. Remember these terms. You will be hearing them many times.

MAGNETIC POLES

When a magnet is dipped in iron filings, most of the filings will adhere to the ends of the magnet in tufts as shown in figure 27. The portion where there is little attraction is called the NEUTRAL REGION or EQUATOR. The areas where the attraction is greatest are called the POLES. The two poles of a bar magnet are distinguished by the position they "seek" or "point" to if the bar magnet is suspended so it can move freely. The one pointing north is called NORTH-SEEKING, or just NORTH pole for short, and the other SOUTH-SEEKING pole, or SOUTH pole. In practice the lines of mag-

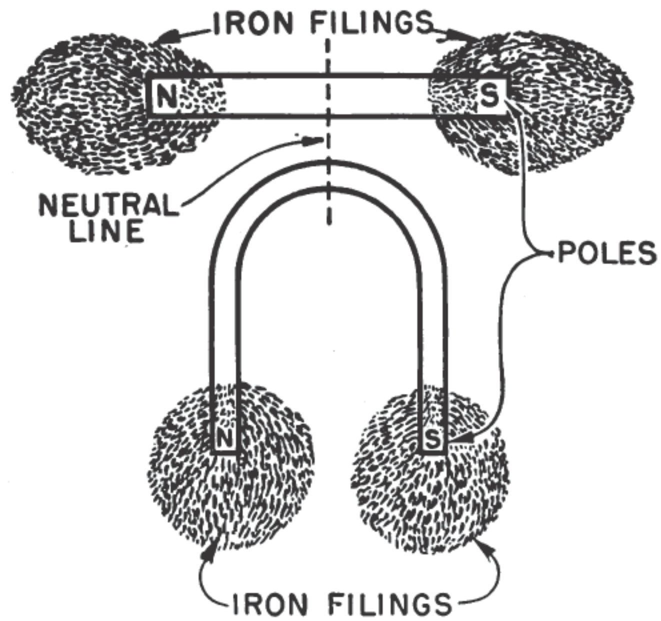


Figure 27.—Magnets holding iron filings.

netism are assumed to leave at the north pole and re-enter the magnet at the south pole, as shown in figure 26. Within the magnet the lines continue from the south pole to the north pole, permitting each line to form a closed loop.

PROPERTIES OF MAGNETIC LINES OF FORCE

Magnetic lines have certain properties that every EM must know. Some are self-evident, others will be explained later.

There is no insulator for magnetic lines; they pass through all materials.

Magnetic lines pass through magnetic materials easily. They tend to crowd into a magnetic material instead of passing through the air.

Magnetic lines tend to shorten themselves as though they were stretched rubber bands.

Magnetic lines flowing in the same direction tend to push each other apart.

Magnetic lines never cross each other.

Each magnetic line forms a complete (closed) loop.

ATTRACTION AND REPULSION OF MAGNETS

Suspend a bar magnet in a manner that leaves it free to swing, and approach each end with the north pole of another magnet. You will find that the north pole of the suspended magnet is repelled and the south pole is attracted. Then if you approach each pole of the suspended magnet with the south pole of the other magnet the north pole is attracted and and the south pole repelled. This demonstrates two very important laws of magnetic attraction.

UNLIKE POLES ATTRACT each other while LIKE POLES REPEL each other.

The ATTRACTION between unlike poles IS EQUAL TO the REPULSION between like poles of the same magnets.

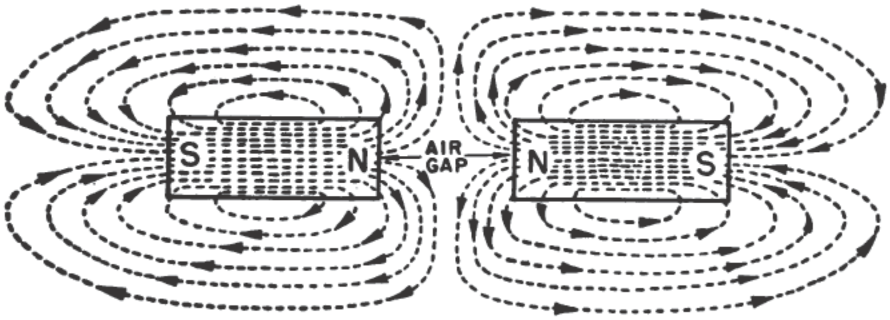
This property of magnetic attraction and repulsion is very important because nearly every piece of rotating electrical equipment depends on this simple principle for ts operation.

Figure 28 shows the reaction between the fields of two bar magnets with like poles near each other. Lines of force cannot cross, so they are forced to turn aside and go in the same direction between the magnets. Since lines of force flowing in the same direction tend to push each other apart, the magnets mutually repel each other.

On the other band, if you turn one of the magnets around so a north pole is opposite a south pole, the lines of force travel directly from the north pole of one into the south pole of the other. See figure 29. Since the magnetic lines behave

as if they are stretched bands, they try to shorten themselves, drawing the magnets together.

Note that the magnetic lines of force are crowded more closely together, and therefore the force of attraction or repulsion is much greater, when the two poles are very nearly touching each other then when they are farther apart.



LINES OF FORCE

Figure 28.—Like poles repel.

Experimentally, the FORCE OF ATTRACTION OR REPULSION between poles of different magnets has been found to be DIRECTLY PROPORTIONAL TO THE POLE STRENGTH of the magnets, and INVERSELY PROPORTIONAL TO THE SQUARE OF THE DISTANCE between them. In other words, while the force between two magnets increases with the strength of the magnets, it will increase at a much faster rate if the distance between the two poles is decreased.

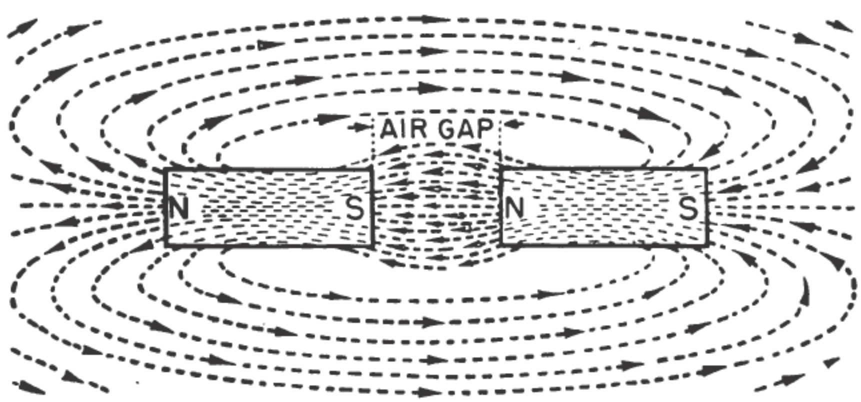


Figure 29.—Unlike poles attract.

WEBER'S THEORY OF THE MOLECULAR NATURE OF MAGNETISM

Stroking a piece of iron or steel with a natural magnet causes the piece of iron or steel to take on the same magnetic properties as when it is stroked with a lodestone. Why is this true? What change takes place in the iron or steel causing it to acquire magnetic properties? Why can't copper, aluminum, wood, and most other materials be magnetized? The answer to these questions is found in the structure of matter. You will recall (from your study of *Basic Electricity*) that all matter is made up of tiny units called molecules, and that one or more atoms make up each molecule. Each atom is composed of a central, positively charged nucleus surrounded by one or more rapidly moving electrons (negative particles) traveling around the nucleus in orbits.

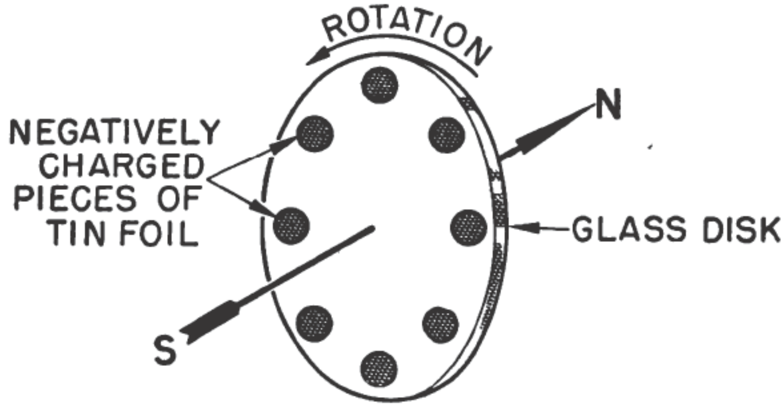


Figure 30.—Experiment for producing a magnetic field.

It has been demonstrated experimentally that electrons in motion create a magnetic field about themselves, and this field is at right angles to the direction of their motion. Here is how it was done. Small circular pieces of tinfoil were glued to the surface of a glass disk near its rim. Large negative charges were placed on the pieces of tinfoil. The glass disk was then placed on a spindle and rotated at high speed by a motor. This rotation of the negative charges set up a magnetic field in the direction shown in figure 30.

This rotating disk with the electrons on the tinfoil is similar to a huge atom with all its electrons lined up in a single plane and rotating at great speed. Thus if the electrons

of an atom all have their orbits of rotation in the same plane, and they all rotate in the same direction like the charges on the disk, the atom will have a magnetic field of definite polarity, as indicated in figure 31.

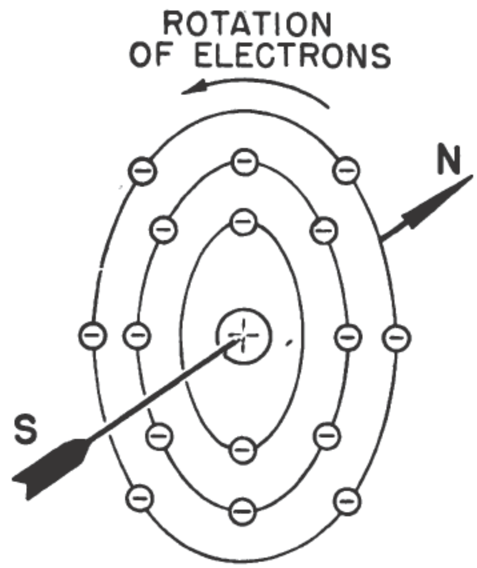


Figure 31.—An atom of a magnetic material.

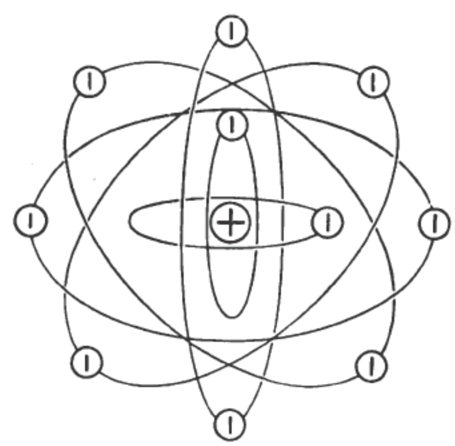


Figure 32.—An atom of a nonmagnetic material.

If, in the atom, the orbits of rotation of the electrons are not in a single plane, a condition as shown in figure 32 exists. Such an atom will not exhibit magnetic properties because the different planes of rotation of the electrons will produce tiny magnetic poles which act in different directions, hence

cancel each other, leaving no over-all magnetic effect in the atom.

It is therefore believed that magnetic materials are made up of atoms similar to the one in figure 31, while nonmagnetic materials are made up of atoms similar to the one in figure 32.

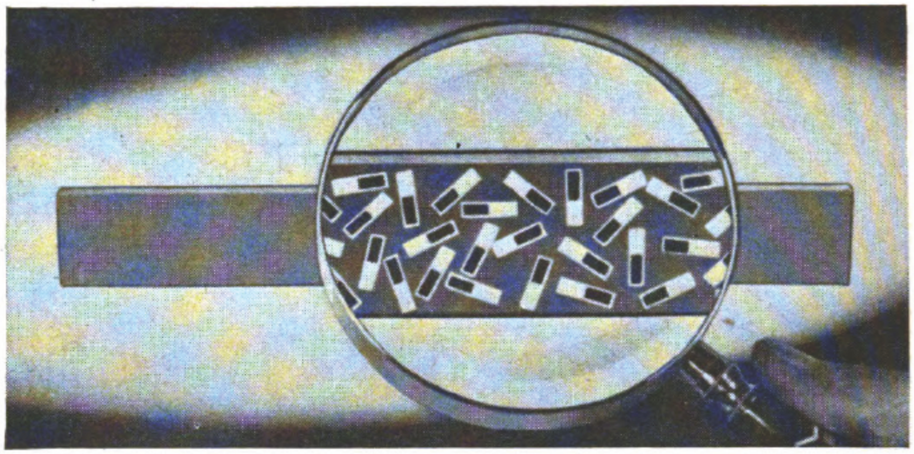


Figure 33.—Molecular arrangement, unmagnetized material.

This theory, that the individual atoms of a magnetic material are tiny magnets, was first evolved by a German scientist named Weber. According to this theory, under ordinary conditions the molecule-magnets are arranged in a haphazard way, as represented in figure 33, hence the north poles (black) and the south poles (white), cancel each other's magnetic force, and so no external magnetic field is produced.

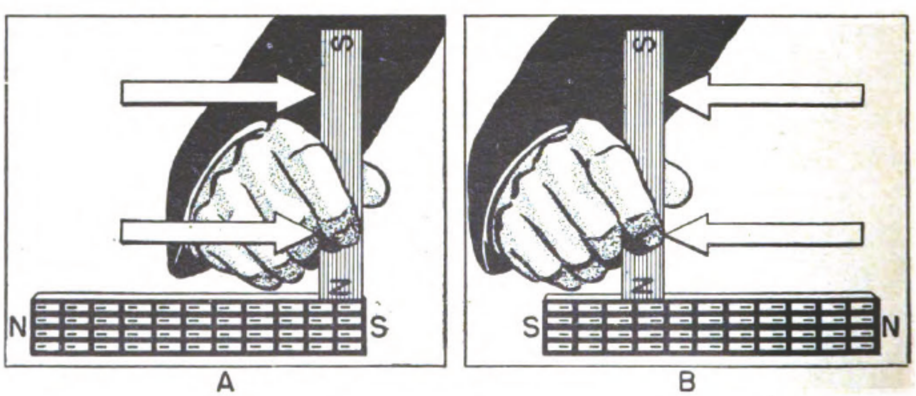


Figure 34.—Magnetizing a bar.

MAGNETIZING A MAGNETIC MATERIAL

Upon applying a magnetizing force, the small molecular magnets tend to arrange themselves so their magnetic axes are parallel, with their like poles all pointing in the same direction, as illustrated in figure 34. The forces of the molecular magnets will then be additive and will produce an external magnetic field.

EFFECT OF BREAKING A BAR MAGNET

The molecular theory of magnetism is supported by the fact that if a brittle bar of hard steel, such as a hacksaw blade, is magnetized and then broken, each piece will be a magnet, as shown in figure 35. Theoretically, if each piece

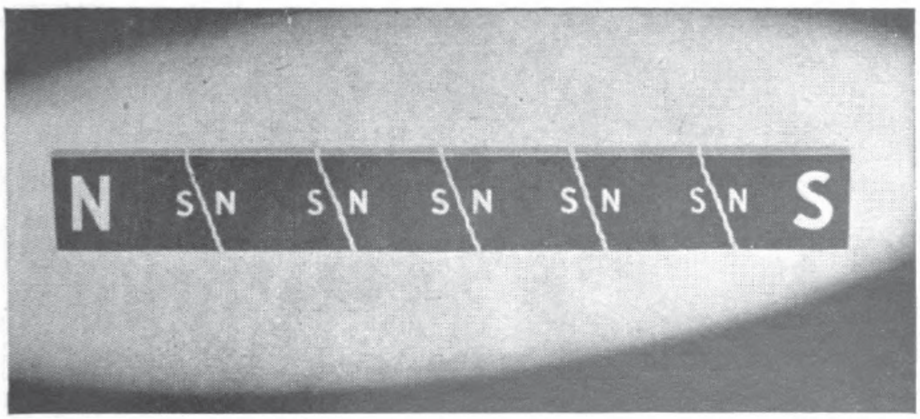


Figure 35.—Effect of breaking a bar magnet.

could be broken up into smaller and smaller pieces until each was a molecule, all would still be individual magnets.

CONSEQUENT POLES

Although the least number of poles a magnet can have is two, it may possess any number greater than two. All these poles, except the two end poles, are called CONSEQUENT poles. If like poles of a weak and a strong magnet approach each other, as a compass needle and a strong permanent magnet, the strong magnet may overcome the weak one and reverse

its polarity. Magnetic needles sometimes have their polarity reversed this way. In making tests with a magnetic needle, always allow it to come to rest in the earth's field first, to see if its polarity markings are correct. (The end which is supposed to point north is often painted blue or black and stamped with an "N".)

If the polarity of a magnet has been reversed this may be detected by plunging its entire length into iron filings or by exploring its field with a small pocket compass. If it has one or more consequent poles it will have a field arrangement as shown in figure 36. Observe how the end marked

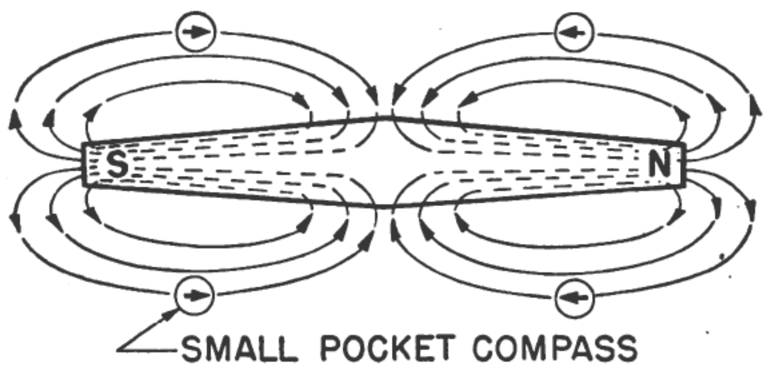


Figure 36.—Discovering consequent poles.

"S" is now a north pole, the same as the end marked "N." Lines of force from the north poles of BOTH ends consequently are forced to enter the center region of the magnet, forming a south pole there.

A reversed magnet like the needle in figure 36 may have its polarity corrected by stroking its entire length in one direction with one pole of a permanent magnet, as shown in figure 34.

PERMANENT ARTIFICIAL MAGNETS

Hard steel is not as easily magnetized as soft steel, but it will retain its magnetism for a longer time. Thus, hard steel makes good permanent artificial magnets. This may be explained by the molecular theory of magnetism. In

hard steel the molecules are tightly packed. When they are swung around to line up with a magnetizing force, there is a high frictional resistance opposing the movement. However, once alined, this same frictional resistance makes it difficult for the molecules to get out of line. Therefore hard steel retains its magnetism well, even though there is normally a lot of motion going on within the individual molecules.

If a permanent magnet is jarred, vibrated, or hammered, some of its molecules will get out of line and weaken its field. If magnets are heated, the motion of the molecules will become violent and this also causes many molecules to get out of line, weakening the field. Permanent artificial magnets are used in galvanometers, voltmeters, ammeters, ohmmeters, meggers, magnetos, loudspeakers, telephone transmitters and receivers, magnetic compasses, and many other devices. The accuracy of these instruments depends on the strength of their permanent magnets remaining constant. Therefore, a permanent magnet or ANY INSTRUMENT CONTAINING A PERMANENT MAGNET SHOULD NOT BE JARRED, VIBRATED, HAMMERED, OR HEATED.

With the magnetic alloys that have recently been developed it is possible to make permanent magnets powerful enough to provide the magnetic fields of small d-c motors. Such motors are used as driving motors in some amplidyne type power drives. Therefore, if you have to assemble or disassemble such a permanent-magnet-field motor, be extra careful, because jarring or hammering the field magnets may kill their magnetism, and this will destroy the usefulness of the motor.

LAMINATED MAGNETS

Thin steel magnets are stronger in proportion to their weight than thick ones. For a given amount of material, a magnet made of several laminations (thin sheets), as shown in figure 37, is more powerful than one made of solid piece of metal. This is due largely to the fact that during heat treatment, the material within the thicker magnets is not properly tempered throughout. The laminated permanent magnets are used mostly in electrical measuring instruments.

TEMPORARY ARTIFICIAL MAGNETS

Soft iron and soft steel are easily magnetized because there is low frictional resistance between the molecules, thus making it easy to swing them into line. However, when the magnetizing force is removed, the motion within the molecules tends to make them lose their alignment. In many

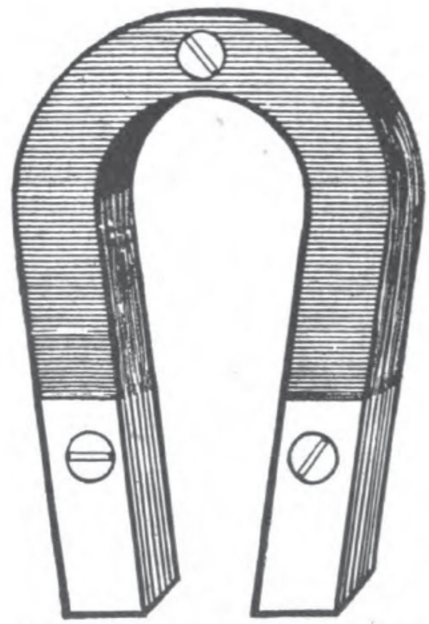


Figure 37.—A laminated horseshoe magnet.

electrical machines such as motors, generators, transformers, relays, and lifting magnets, a temporary magnet is desirable, and therefore they use temporary artificial magnets.

MAGNETIC INDUCTION—MAGNETIC MATERIALS ATTRACTED BY A MAGNET

A piece of unmagnetized soft iron, placed in the magnetic field of a permanent magnet, assumes the properties of the magnet; that is, it becomes magnetized. The magnetizing of a piece of iron or steel by the field of a nearby magnet is called MAGNETIC INDUCTION. Magnetic induction in a magnetic material may be explained by the properties of magnetic lines and the molecular theory of magnetism in this way: Magnetic lines tend to pass through a magnetic material rather than through air, as shown in figure 38. When the

lines of the magnetic field pass through the iron, the molecules readily line up parallel with the lines of force, and with their north poles pointing in the direction that the lines of force are traveling through the iron. Thus, magnetism is

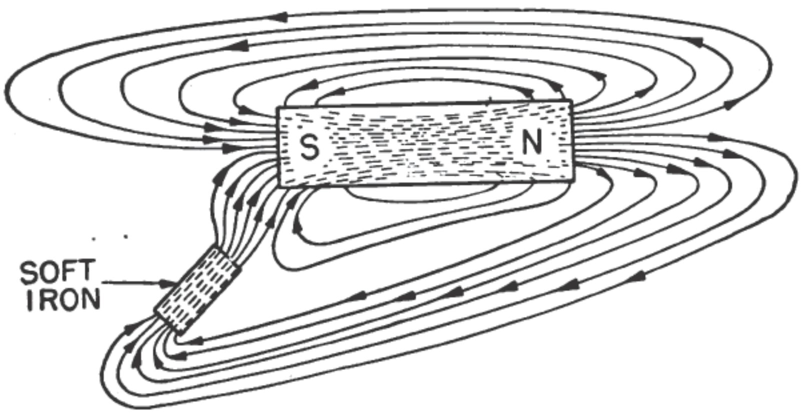


Figure 38.—Effect of a soft iron bar in a magnetic field.

INDUCED in the iron. Remembering that where lines of force leave the magnet in a north pole and where they enter is a south pole, it will be observed that an unlike pole is formed in the end of the iron bar next the permanent magnet. Between unlike poles the magnetic lines act as stretched rubber bands, so the unlike poles attract. Therefore, the iron is attracted to the permanent magnet.

MAGNETIC SCREENING OR SHIELDING

No material is known that will effectively insulate against magnetic flux. Because of this, it is sometimes difficult to eliminate the effect which stray magnetic fields have upon instruments such as magnetic compasses, ammeters, voltmeters, etc. The stray magnetic fields in the vicinity of generators, motors, transformers, and cables carrying large currents will therefore affect seriously the accuracy of these instruments. Since lines of flux cannot be insulated, it is necessary to use something that will divert flux around the instrument. This is accomplished by placing a soft iron case, called a MAGNETIC SCREEN OR SHIELD, about the instrument. Since the flux flows more readily through the

iron than through the air, the instrument is effectively shielded, as shown in figure 39. Even with a shield a few lines may still pass through the instrument so all instruments,

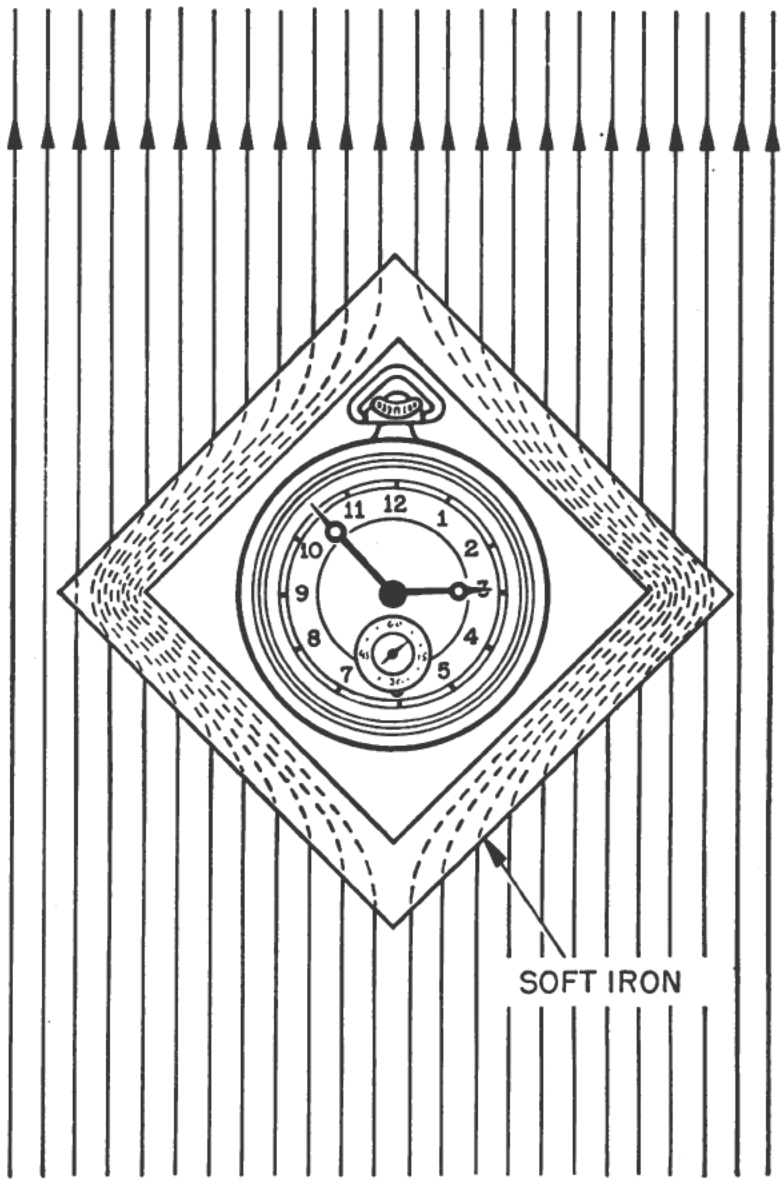


Figure 39.—Magnetic screen.

even if magnetically shielded, should be kept away from strong magnetic fields as far as possible.

THE MAGNETIC COMPASS

A magnetic compass is merely a thin bar magnet, accurately balanced and suspended on a pivot so that it may

rotate freely. This thin bar, usually called the COMPASS NEEDLE, always tends to align itself parallel to the lines of force of the field in which it is placed. The north end, usually painted blue or black, points in the direction the magnetic lines are flowing, as shown in figure 40.

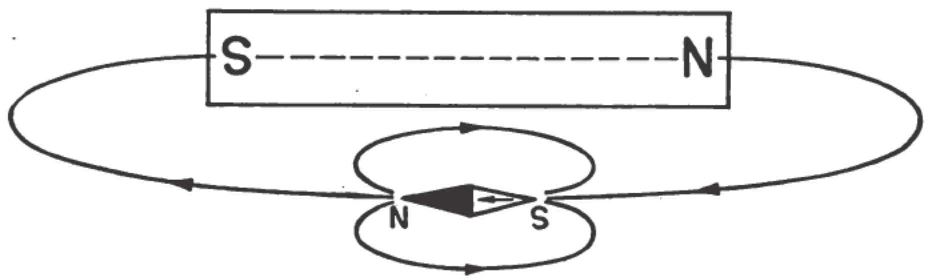


Figure 40.—Position of a compass needle.

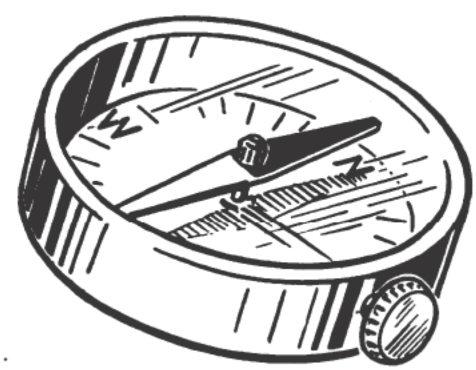


Figure 41.—Pocket compass.

A pocket compass of the type shown in figure 41 is used to detect the presence of a magnetic field or to determine its polarity. It is therefore often used to determine the polarity of poles in a generator or motor, which in turn will indicate whether the field coils are connected correctly.

DETERMINING POLARITY OF UNMARKED MAGNETS

The fact that unlike poles attract and like poles repel can be used to determine whether a piece of material is magnetized and, if magnetized, its polarity.

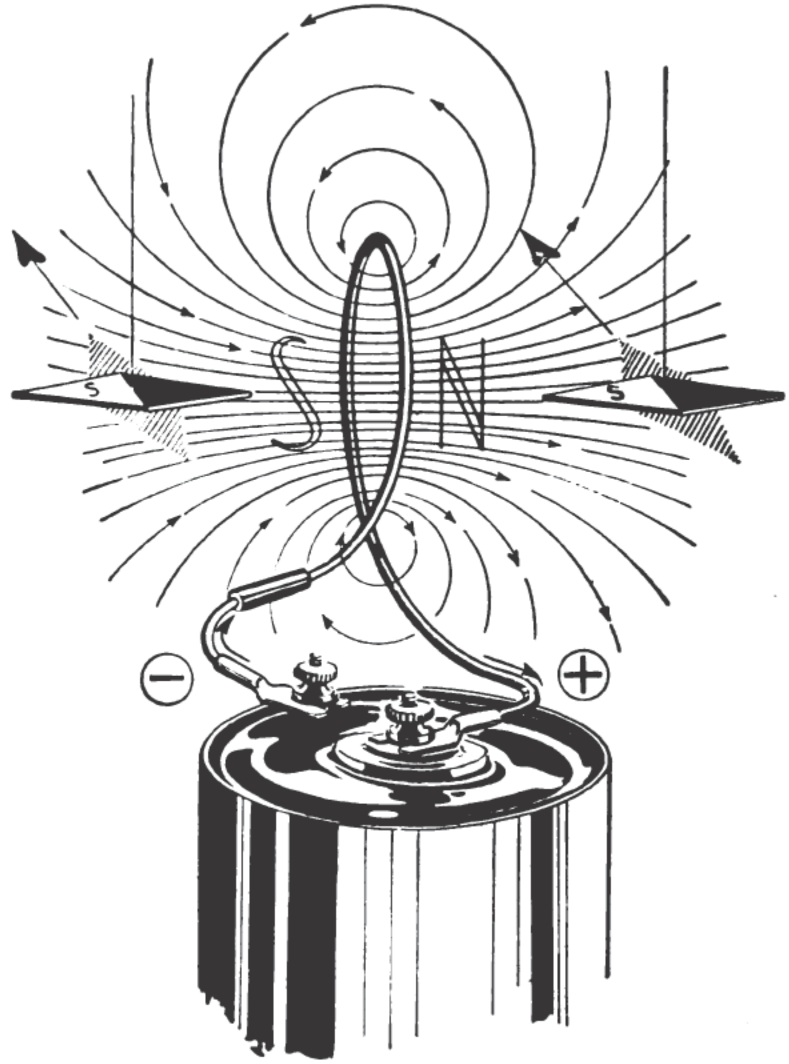
If a compass is brought near one end of a supposed magnet, the near end of the compass needle will be attracted or

repelled. If the north pole of the needle swings toward the object, the end nearest the compass appears to be a south pole. However, bear in mind that either end of a compass needle will be attracted to a piece of unmagnetized iron or steel. As a check, place the other end of the compass needle near the unmarked magnet. It will be repelled if the unmarked magnetic material is actually magnetized.

QUIZ

1. What other materials besides iron show magnetic properties?
2. What materials have stronger magnetic properties than iron?
3. Name three nonmagnetic materials.
4. How do nonmagnetic materials differ from nonconductors of electricity?
5. If you have a magnetic material that is not magnetized, name two ways in which a magnet could be used to produce magnetism in it.
6. Complete the following sentences:
   a. Magnets act as if magnetic lines of ------ existed between poles.
   b. The space in which magnetic lines are present is called the magnetic ------.
   c. The magnetic lines through a particular area comprise the magnetic ------.
   d. The path magnetic lines follow is called a magnetic ------.
7. Complete the following sentences:
   a. Flux density indicates the ------ of a magnetic field.
   b. Flux density is expressed in ------ per square inch.
   c. The unit of flux density is the ------.

8. Complete the following sentences:
   a. Magnets attract magnetic materials because magnetic lines tend to ------ themselves.
   b. Magnetic shielding is difficult because magnetic lines pass through ------ materials.
   c. An instrument can be partly shielded from magnetic fields by a housing of magnetic materials because magnetic lines pass through magnetic materials ------.
   d. Magnets repel each other because magnetic lines flowing in the same direction tend to ------ each other ------.
   e. Magnetic lines never ------.
   f. Each magnetic line forms a complete ------.
   g. Like magnetic poles will ------ each other.
   h. Unlike magnetic poles ------ each other.
   i. The force of attraction between magnets is ------ proportional to the pole strength of the magnets.
   j. The force of attraction or repulsion between magnets is ------ proportional to the square of the distance between them.
9. How does the arrangement of electrons within the atom differ between magnetic and nonmagnetic materials?
10. What does a magnetizing force do to the molecular magnets of a magnetic material?
11. According to the molecular theory of magnetism, why is hard steel more difficult to magnetize then soft iron?
12. Instruments using permanent magnets should not be jarred, hammered, or heated because jarring, hammering and heat do what to the permanent magnet?
13. Using a magnetic compass, how would you detect if a magnetic material is magnetized?



CHAPTER 3

ELECTROMAGNETISM AND MAGNETIC CIRCUITS

OERSTED'S DISCOVERY

In 1819, Hans Christian Oersted, a Danish scientist, made one of the most important single discoveries in the field of electricity. While experimenting he accidentally brought a small compass near a wire carrying an electric current and noted that the needle no longer assumed its usual north-south direction, but aligned itself at right angles to the wire. By this observation he had discovered the principle of electromagnetism—namely, that A MAGNETIC FIELD ALWAYS SURROUNDS A CONDUCTOR CARRYING A CURRENT. While he

probably didn't realize its importance, Oersted had discovered the key to the vast fields of commercial electricity.

MAGNETIC FIELD AROUND A CURRENT-CARRYING CONDUCTOR

You learned in the chapter on magnetism that whenever electrons move a magnetic field is created at right angles to their direction of motion. Therefore, whenever a current flows, a magnetic field always exists around it. If the conductor in which the current flows is a straight wire, the field takes the form of concentric circles or rings of magnetic force around the wire, as shown in figure 42. You can check

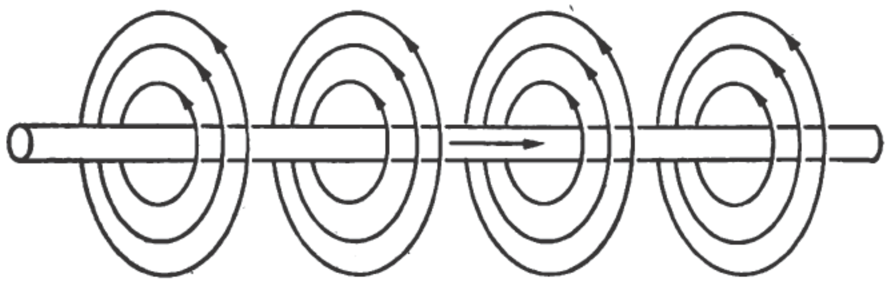


Figure 42.—Magnetic field about a conductor carrying a current.

this experimentally with a small pocket compass. Since a compass needle always aligns itself parallel to magnetic lines

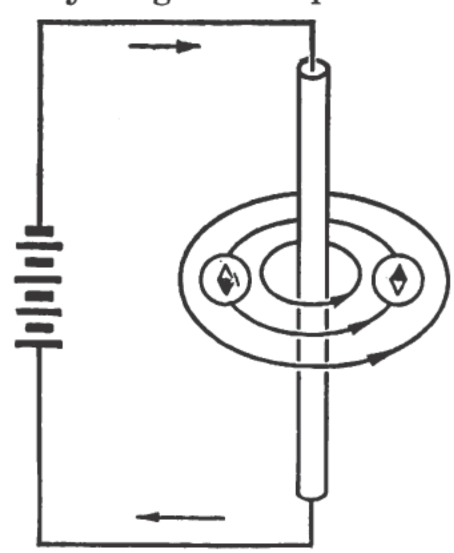


Figure 43.—Experiment to detect the field about a current-carrying conductor.

of force, the needle also will be at right angles to a current-carrying conductor. You can perform this experiment with a dry cell, a piece of wire, and a compass as shown in figure 43.

If the direction of current in the conductor is reversed, the compass needle will reverse, indicating that the magnetic lines circling the conductor are in the opposite direction.

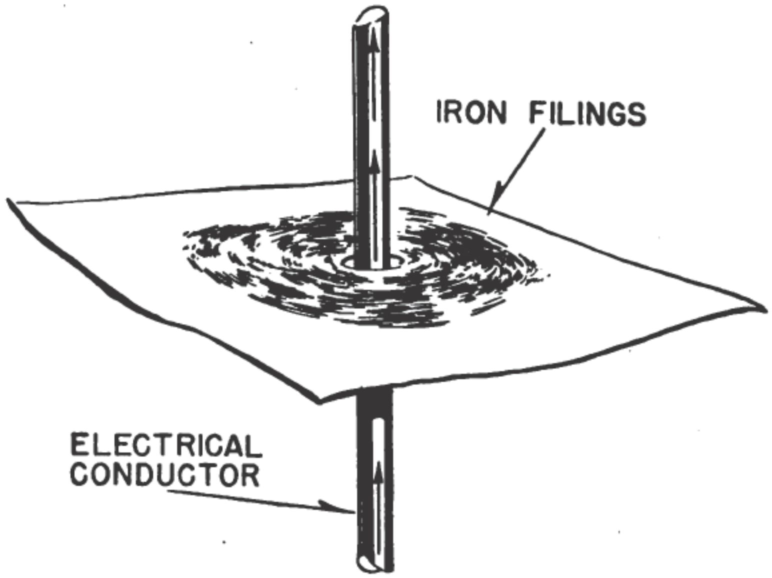


Figure 44.—Experiment to show circular nature of magnetic field around a current-carrying conductor.

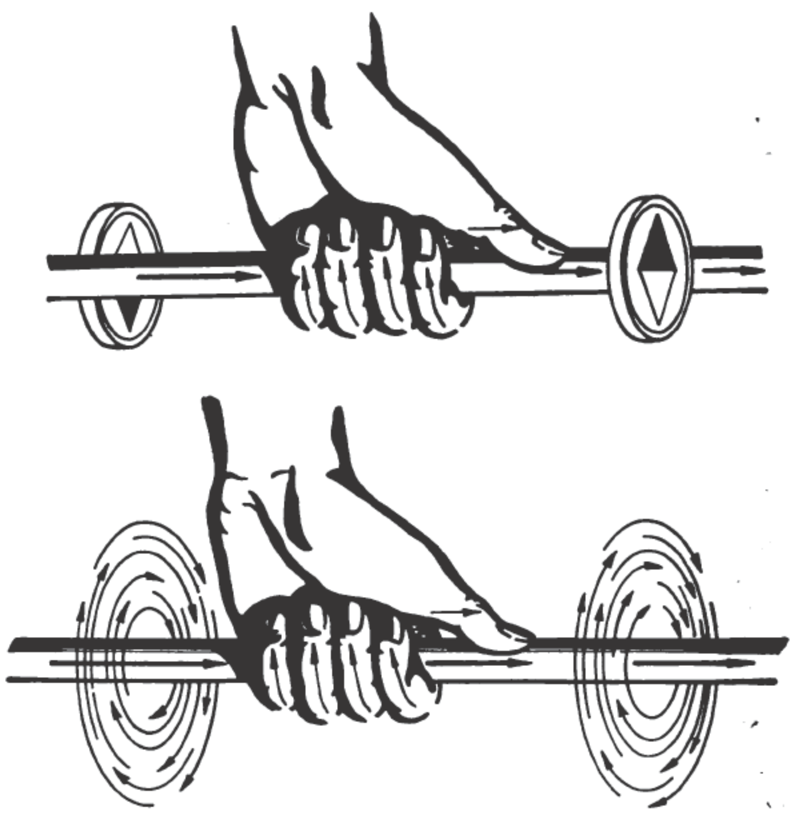


Figure 45.—Left hand rule for a conductor.

If, as in figure 44, a current is sent through a conductor surrounded by a cardboard on which iron filings have been sprinkled, the filings will assume a circular pattern. This shows clearly the circular nature of the magnetic field around a conductor carrying current.

LEFT HAND RULE FOR A CURRENT-CARRYING CONDUCTOR

Here is an important rule. You have heard it before, but review it again.

IF A CURRENT-CARRYING CONDUCTOR IS GRASPED IN THE LEFT HAND WITH THE THUMB POINTING IN THE DIRECTION OF ELECTRON FLOW (NEGATIVE TO POSITIVE), THE FINGERS WILL POINT IN THE DIRECTION OF THE MAGNETIC LINES OF FLUX. Figure 45 shows the application of the left hand rule.

Notice

Years ago, scientists named the COPPER terminal of a primary cell the POSITIVE terminal and the ZINC the NEGATIVE, and said the direction of current flow was from POSITIVE to NEGATIVE. Modern experiments have shown that a current of electricity is really a flow of electrons, and the direction of flow is from NEGATIVE to POSITIVE. Nevertheless the old theory is still used in many electrical textbooks and in some Navy manuals.

If you run across the old theory, don't let it confuse you. In those cases where you find that current is traced from positive to negative, simply use the OPPOSITE HAND from the one used in this book. Your answer will then be correct.

Throughout this book all explanations are based on the present-day idea—that current flow is a flow of electrons, from NEGATIVE to POSITIVE.

LEFT HAND RULE TO FIND THE DIRECTION OF CURRENT

By using a pocket compass and the left hand rule you can determine the direction in which the current is flowing in a conductor. Grasp the conductor in the left hand with the FINGERS pointing in the same DIRECTION as the NORTH POLE of the compass; the THUMB will then point IN the DIRECTION in which the CURRENT is flowing.

In electrical diagrams arrows are usually added to mark the direction of current flow. This works well along the length of the wire, but where cross-sections of wire are shown, a special veiw of the arrow must be used. Look at figure 46.

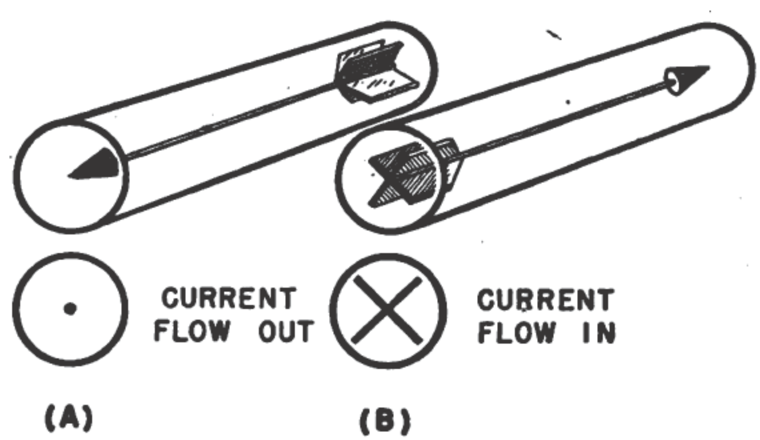


Figure 46.—Current flowing in and out of a conductor.

The left drawing shows an arrow coming out of the wire. If you cut this wire, and look at it from the end, you will see the head of the arrow coming out of the wire. So a DOT (·) is the symbol used to indicate the current coming OUT of a wire. When the current is flowing into the wire, the cross-section shows the feathered tail of the arrow. So a CROSS (+) representing the tail of the arrow is used to indicate a current going INTO a wire.

Figure 47 shows cross-section views of two conductors. Both directions of current flow are indicated. Use the left-hand rule to check these labels. Your thumb should point

up out of the page for the left-hand drawing, and down into the page for the right-hand drawing.

THE MAGNETIC FIELD AROUND A SINGLE CONDUCTOR

The greater the current in the conductor, the stronger will be the magnetic field around it and the further out this field will extend from the conductor. You can see why this is so

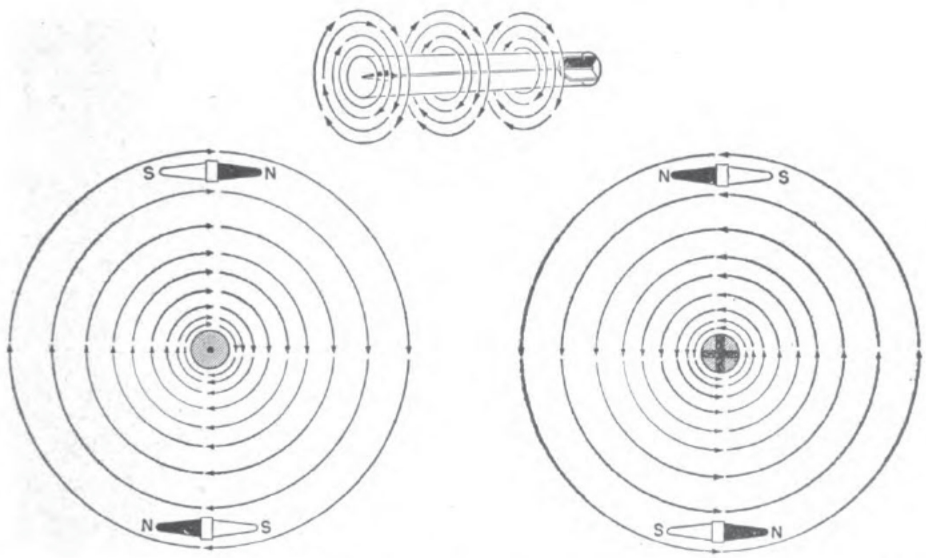


Figure 47.—Cross-sectional view of a magnetic field around a conductor.

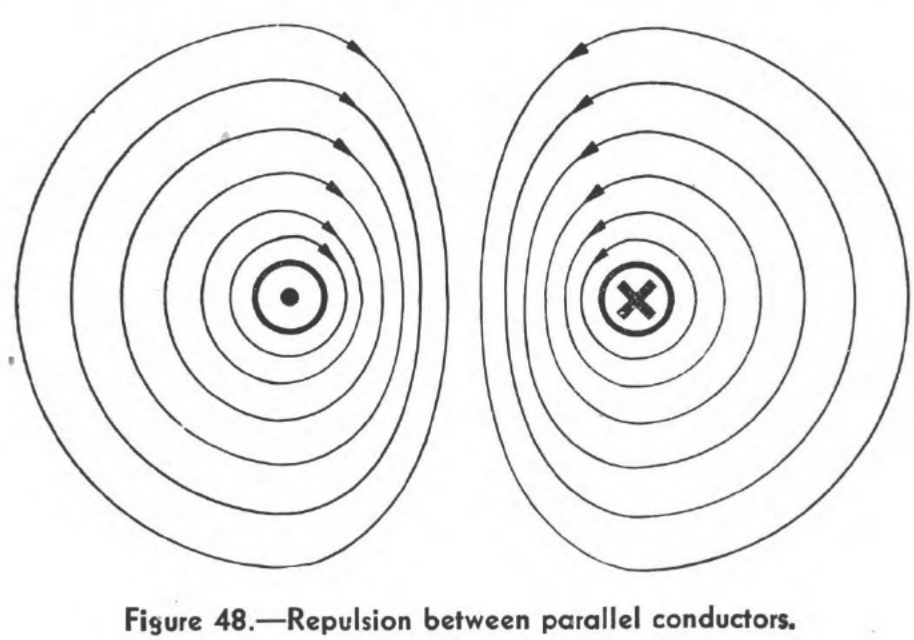


Figure 48.—Repulsion between parallel conductors.

from the following explanation of how the field is built up. The lines of force are assumed to start as a dot in the center of the conductor. When the current starts to flow, these circular lines of force expand from this dot. As the current increases new lines are formed. Since the magnetic lines of force flowing in the same direction tend to push each other apart, the new lines of force cause those already formed to expand outward. Therefore the greater the current the farther the field extends outward. The field surrounding a conductor carrying a large current may extend outward several feet. When the current ceases to flow the magnetic field disappears, as if the lines of force had collapsed back into the center of the conductor.

MAGNETIC FIELDS ABOUT PARALLEL CURRENT-CARRYING CONDUCTORS

Suppose you have two long conductors arranged parallel and close together. If the two conductors are carrying CURRENTS in OPPOSITE directions the magnetic fields around the wires will be as shown in figure 48, with the lines of force of both magnetic fields flowing in the same direction, and the two fields add in the space between both wires. Since lines of force traveling in the same direction tend to push each other apart, this will result in a REPULSION BETWEEN THE TWO CONDUCTORS.

Figure 49 shows two parallel conductors with CURRENT flowing IN the SAME DIRECTION in each conductor. In the space between the two conductors the lines of force for both conductors are now in opposite directions, and cancel each other. But the lines of force surrounding both conductors remain. Since these lines of force act like elastic bands trying to shorten themselves, they tend to PULL THE CONDUCTORS TOGETHER.

The two preceding paragraphs can be summarized into the following rule: Conductors carrying currents in the SAME direction ATTRACT one another, and conductors carrying currents in OPPOSITE directions REPEL one another.

This rule is sometimes very impressively demonstrated in modern, large-capacity power systems. In some cases

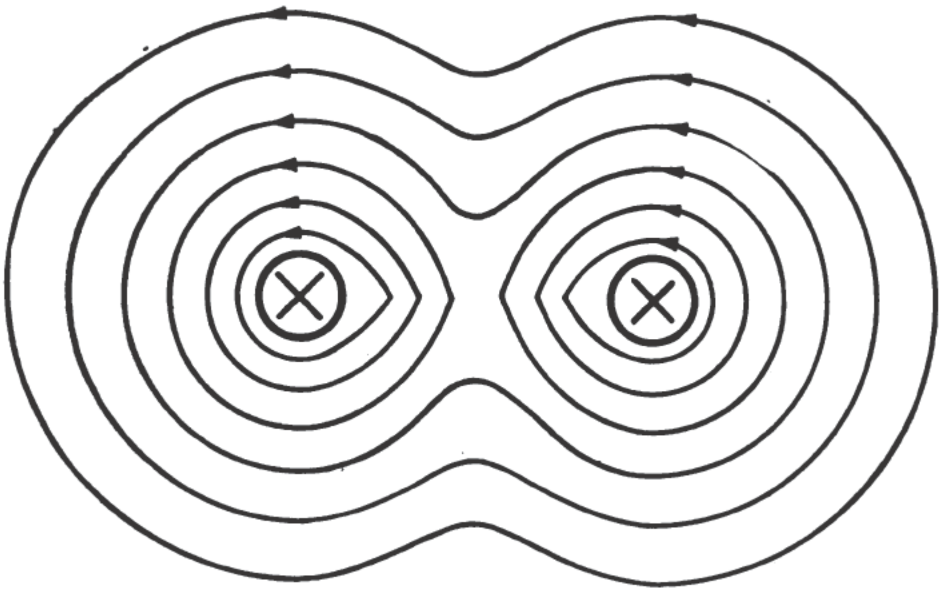


Figure 49.—Attraction between conductors.

bus bars have been wrenched from their clamps, and even transformers coils have been pulled out of place and the transformers wrecked, by the magnetic forces produced by the extremely large currents which result from a short circuit.

MAGNETIC FIELD ABOUT A CURRENT-CARRYING LOOP

From your study of magnetism you learned that a magnet's lines of force travel in a closed loop, from north to south

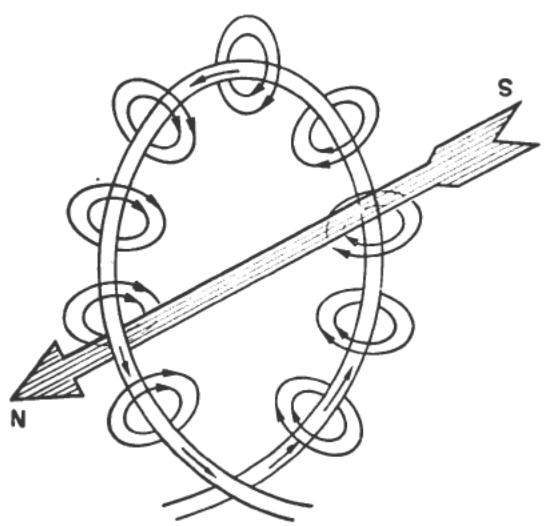


Figure 50.—Magnetic field about a loop.

outside the magnet, and from south to north inside. If a current-carrying conductor is formed into a loop then, as

shown in figure 50, all the lines of force are entering on one side of the loop and leaving on the other side. Thus with a current of electricity you have produced a magnet (called an ELECTROMAGNET) with a definite north and south pole.

Figure 51 shows an interesting comparison between the magnetic field set up around a current-carrying loop of wire

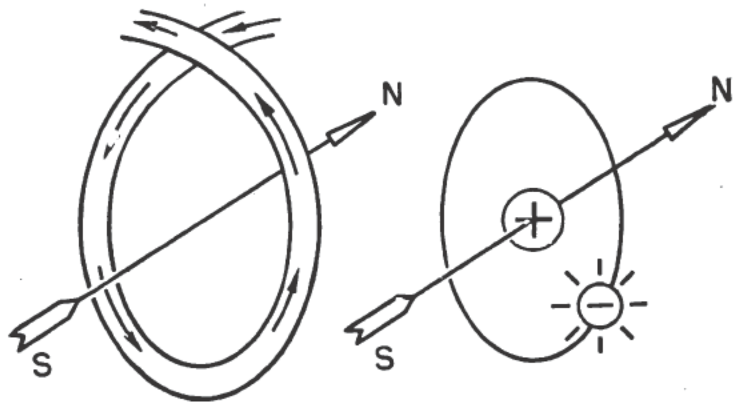


Figure 51.—Comparison of a current-carrying loop and an atom.

and the field set up by an electron rotating around the nucleus of an atom. The electron in its motion about the nucleus creates a magnetic field in much the same way as the electrons circulating through the wire.

COILS

When it is desired to produce a magnetic field by an electric current, the wire is formed into a coil instead of a single loop. A conductor wound as a coil (helix) is called a SOLENOID. The solenoid may thus be considered as consisting of a large number of single loops, all connected in series and placed close together as in figure 52. The solenoid may have a winding of one or several layers.

Figure 52 shows the magnetic field set up about a current-carrying coil. Since the current flows in the same direction in each turn, you have the effect of parallel conductors carrying currents in the same direction. In the spaces between turns the flux lines are opposite and cancel, so if the turns are close together only a small amount of flux passes through between the turns, most of the flux being forced to pass around all the turns and through the center

of the coil, concentrating the flux at the center. As in a permanent magnet, the end from which the flux lines leave the coil is called the NORTH pole.

LEFT HAND RULE FOR A CURRENT-CARRYING COIL

There is a left hand rule for coils similar to the one for conductors. This rule is: Grasp the coil in the left hand with the FINGERS pointing in the direction of the ELECTRON

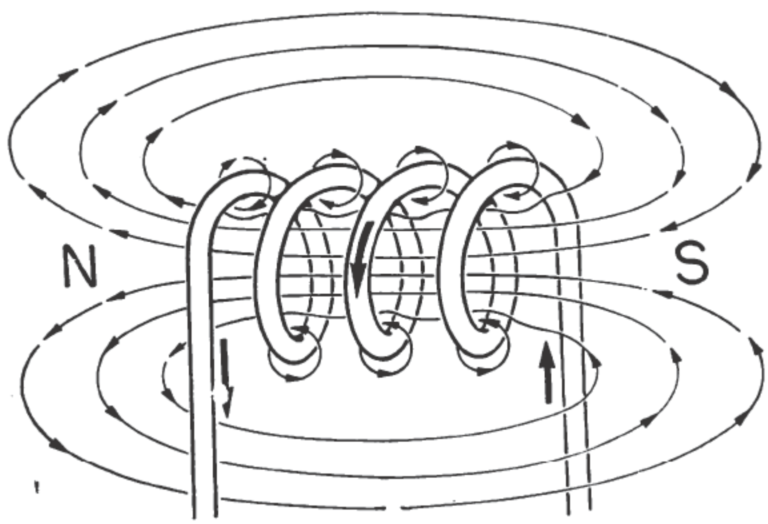


Figure 52.—Magnetic field surrounding a solenoid.

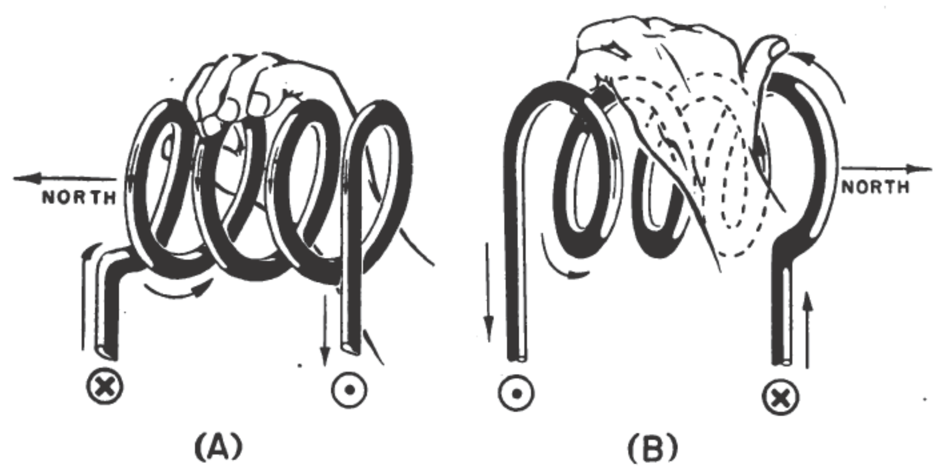


Figure 53.—Left hand rule for coils.

FLOW; the THUMB will then point in the direction of the NORTH pole end of the coil. Figure 53 illustrates an application of this rule.

SOLENOID AND PLUNGER

You have learned by experience that a piece of soft iron is attracted to a permanent magnet. Now if you place the soft iron bar in the field of an electromagnet produced by current-carrying coil, you will get similar results. As shown in figure 54, the lines of force will flow through the soft iron and magnetize it temporarily. Since the lines of force tend to shorten themselves, the iron bar is pulled toward the coil. If the iron bar is free to move, it will be drawn into the coil to a position near the center, where the pull is greatest. Such a solenoid with a moving iron plunger is sometimes called a SUCKING COIL, and the plunger is called a CORE.

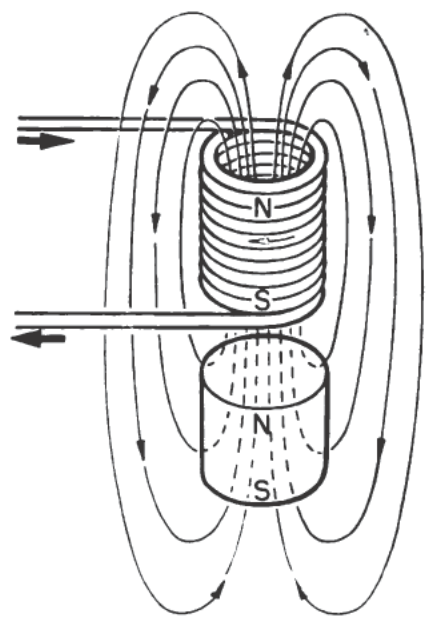


Figure 54.—Solenoid with an iron core.

The solenoid-and-plunger principle is employed extensively aboard ships to operate the feeding mechanism of carbon arc searchlights; to open circuit-breakers automatically when the load current becomes excessive; to close switches for motorboat starting; to fire guns; and to operate flood valves, magnetic brakes, and many other devices.

ELECTROMAGNETS

Strictly speaking, a single loop of wire or any coil carrying current is an electromagnet. However, it is general practice

to speak of a coil of wire having a soft iron core as an ELECTROMAGNET. The soft iron core offers less opposition to the flow of magnetic lines than does air. Therefore, a coil having an iron core and surrounded by an iron jacket will have a much stronger magnetic field than the same coil without an iron core. Generators, motors, relays, electric bells, buzzers, dynamic loudspeaker fields, are a few of the many machines that use electromagnets.

MAGNETIC CIRCUITS

A MAGNETIC CIRCUIT is the COMPLETE PATH TAKEN BY MAGNETIC LINES OF FORCE in flowing out from their starting point, the north pole, through the adjoining magnetic conductor or nonmagnetic materials, then into the south pole and back through the magnet to the north pole. In figure 55 the path of the broken lines (indicating lines of flux)

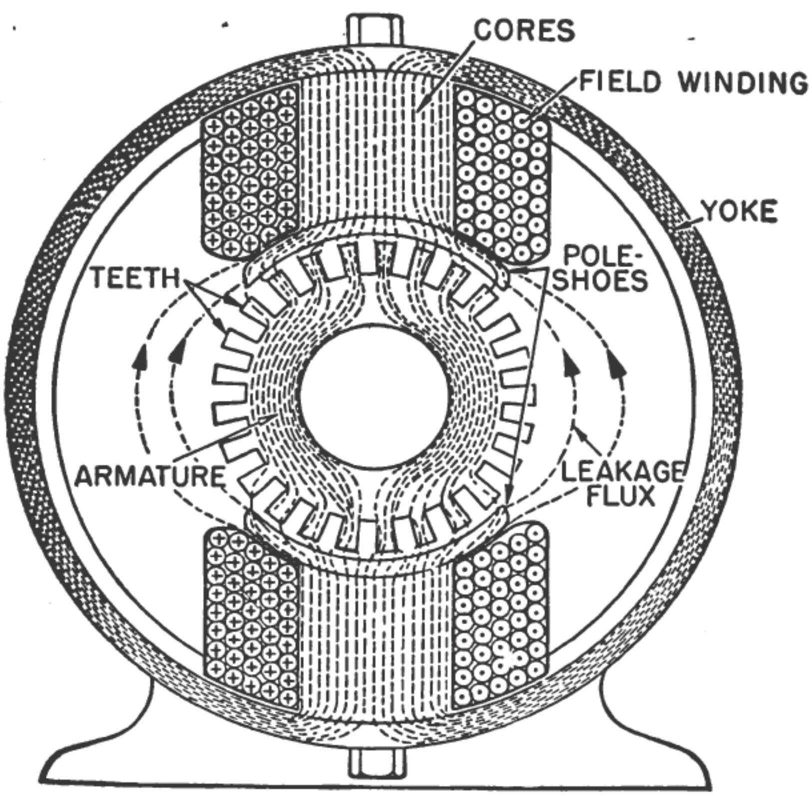


Figure 55.—Magnetic circuit in a bipolar generator.

running through one pole, around the yoke to the other pole, then through the armature and finally back to the starting point, is an example of a magnetic circuit.

In studying electric circuits you learned that the basic factors of every complete curcuit are: voltage, resistance of the conductor and the current. Magnetic circuits have similar factors; MAGNETOMOTIVE FORCE, RELUCTANCE, PERMEABILITY, and FLUX.

MAGNETOMOTIVE FORCE

MAGNETOMOTIVE FORCE (mmf) is similar to electromotive force, in that it causes the flux to flow in the magnetic circuit. In electromagnets, the mmf comes from the current flowing through the coil. The NUMBER OF TURNS of wire in a coil MULTIPLIED BY the NUMBER OF AMPERES flowing expresses the mmf of the coil in AMPERE-TURNS. You can increase the "magnetic pull" of a solenoid by increasing the number of turns of wire in the coil, by increasing the number of amperes flowing through it, or both. One AMPERE-TURN of mmf is equivalent to a SINGLE LOOP of wire CARRYING a current of ONE AMPERE. Another UNIT of magnetomotive force used is the GILBERT. One ampere turn equals 1.257 Gilberts.

RELUCTANCE

The RELUCTANCE in a magnetic circuit is similar to the resistance in electrical circuits. It is the opposition offered to the flow of magnetic flux. Air offers greater reluctance to the flow of magnetic lines than any other common form of matter and soft iron offers the least. Various kinds of iron and steel offer varying degrees of reluctance and each has its use in the design of electrical machinery and apparatus. A unit of reluctance has not been officially adopted but one sometimes used is referred to by the symbol CGS and is equivalent to the reluctance offered to the flow of magnetic lines of force by a cubic centimeter of air.

PERMEABILITY

PERMEABILITY is the RATIO OF the ABILITY of any material to conduct magnetic lines of force to the ability of a mass of air of the same shape and size TO CONDUCT FLUX. Air is considered the standard unit and is given the value of 1.

As an example, if the permeability of iron is 50, the ratio of flux conductivity between iron and air is 50 to 1, and a cubic inch of iron will conduct 50 times as many lines of force as a cubic inch of air. Permeability of matter is of utmost importance to the designer of electrical machinery but as Electrician's Mate 3d class, it is only necessary to understand the ratio that the word represents.

FLUX

FLUX corresponds to the current in an electric circuit. Flux may be considered as the NUMBER OF MAGNETIC LINES OF FORCE that flow in a magnetic circuit. The UNIT of flux is the MAXWELL, but this term is seldom used and the amount of flux in a magnetic circuit is usually referred to as so many lines of force, or LINES OF MAGNETIC INDUCTION.

OHM'S LAW FOR MAGNETIC CIRCUITS

There is a law for the flux in a magnetic circuit which is similar to Ohm's law for the current in an electric circuit. It states: FLUX IS DIRECTLY PROPORTIONAL TO THE MAGNETOMOTIVE FORCE AND INVERSELY PROPORTIONAL TO THE RELUCTANCE OF THE MAGNETIC CIRCUIT. Thus:

MAGNETIC CIRCUIT	ELECTRICAL CIRCUIT
$\text{Flux}=\dfrac{\text{Magnetomotive force}}{\text{Reluctance}}$	$\text{Current}=\dfrac{\text{Electromotive force}}{\text{Resistance}}$

FLUX DENSITY is expressed as the number of lines of force found in a unit of cross section area, such as square inch or square centimeter. The UNIT of flux density is the GAUSS, defined as one flux line per square centimeter.

SATURATION

In the electric circuit, the greater the emf the more current flows in the circuit. But the Ohm's law for a magnetic circuit holds good only up to a certain maximum flux density. When this flux density is reached, the application of any additional magnetomotive force will not produce any appreciable increase in flux. The material is then said to be SATURATED. The flux density at which saturation is reached is different for different materials. Saturation is important

in the design of electrical machinery, because it is the main factor in determining how large an iron core must be used for a certain size motor, generator, or transformer.

RETENTIVITY AND RESIDUAL MAGNETISM

RETENTIVITY is the property of some magnetic substances to retain part of their magnetism after the magnetomotive force has been removed. The flux retained is called the RESIDUAL magnetism. The property of retentivity is desirable in some d-c electrical generators, as explained in Chapter 6. In a-c devices retentivity is objectionable because a magnetomotive force must be developed to destroy the residual magnetism. Not only is energy used up in creating this magnetomotive force, but this energy is used up in heating the magnetic material, and this heat may injure the insulation of the electromagnet winding. All iron and steel do not have retentivity in equal amounts. It is highest in hard steel.

MAGNETIC LOSSES

Many high sounding names are connected with magnetic losses but only a brief explanation of these losses is necessary at this time. Magnetic losses are the result mainly of the friction between the atoms or molecules when they are forced into alignment by the magnetic lines of force. This friction is called HYSTERESIS, and overcoming it actually produces heat in the magnetic material, an evidence of energy loss. Vibration and chattering of the magnetic material are often signs of a magnetic loss. Beyond this explanation do not worry about magnetic losses as they are accounted for in the design of the equipment.

MAGNETIC ADJUSTMENTS

Unlike electrical circuits, magnetic circuits are designed in most cases so as not to require any adjustment, and remain as installed. Their presence, use, and basic theory should be understood, but do not worry about altering or adjusting them. When it is necessary to make repairs or adjustments consult the manufacturer's instructions for the equipment and be guided by experienced electrician's mates on your ship.

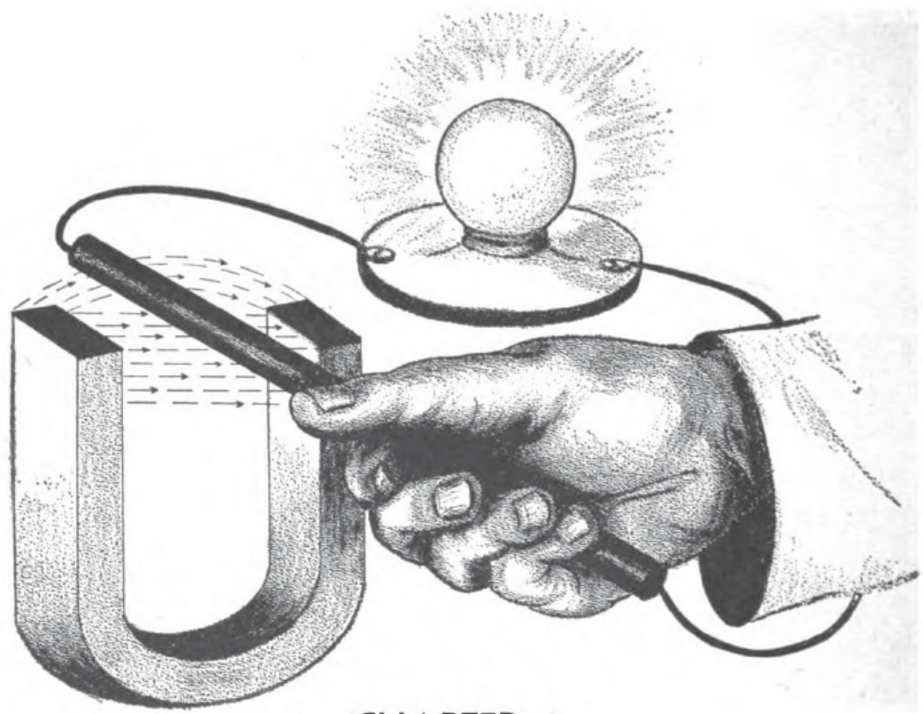
QUIZ

1. How did Oersted discover that a magnetic field exists around a wire carrying an electric current?
2. What is the shape or pattern of a magnetic field around a wire carrying an electric current?
3. If you reverse the current in a wire how does that change the field around the wire?
4. Complete the following statements: The left hand rule for the field around a conductor says: When the thumb points in the direction of ------ the fingers point in the direction of ------.
5. How does the field around a conductor carrying current change with distance from the conductor?
6. Complete the following statements:
   (a) When two parallel conductors have currents flowing in opposite directions, their magnetic fluxes ------ in the space between them.
   (b) When two parallel conductors have currents flowing in opposite directions, their magnetic fields produce a force of ------.
   (c) When two parallel conductors carry currents in the same direction their magnetic fluxes in the space between them ------.
   (d) When two parallel conductors carry currents flowing in the same directions, their magnetic fields produce a force of ------ between the conductors.
7. Into what shape would you bend a current-carrying wire so that it would produce the same kind of a field as a bar magnet?
8. A current-carrying coil shaped to produce a magnetic field like the field of a bar magnet is called a ------.
9. At what place about such a coil is the field strongest?
10. Complete the following statements: When a coil carrying current is grasped in the left hand, so the thumb points in the direction of the ------, the fingers point in the direction of the ------.

11. Complete the following statements:
   (a) If an iron core is placed near a current-carrying coil, the field of the soil will produce magnetic ------ in the core.
   (b) If an iron core is placed near a current-carrying coil the core will be ------ by the coil.
12. Name three applications, in electrical gear, for the principle of a current-carrying coil acting on an iron core.
13. Complete these statements:
   (a) The current-carrying coil and iron core combination is called an ------.
   (b) The closed-loop path followed by magnetic lines is called a magnetic ------.
14. Complete the following statements:
   (a) The greater the magnetomotive force, the greater the ------ in a magnetic circuit.
   (b) The greater the current in the coil of an electromagnet, the ------ the magnetomotive force.
   (c) The greater the number ot turns in the coil of an electromagnet, the ------ the magnetomotive force.
   (d) To increase the magnetic pull of a current carrying coil you
      (1) ------ the number of turns.
      (2) ------ the current.
   (e) The number of turns of wire in a coil times the number of amperes flowing in it is called the ------ of the coil.
   (f) The unit of magnetomotive force is called the ------.
15. Opposition to the flow of magnetic flux in a magnetic circuit is called ------.
16. The ratio of the ability of a material to conduct magnetic flux compared to air as a flux conductor is called the material's ------.
17. Complete the following statements:
   Flux produced in a magnetic circuit is
      (a) ------ proportional to the magnetomotive force.
      (b) ------ proportional to the reluctance.
      (c) Ohm's law for a magnetic circuit can be expressed by the equation

Flux= ------

18. Complete the following statements:
   (a) The flux density at which an increase in magnetomotive force will not produce much increase in flux is called the ------ density.
   (b) Ability of a material to retain magnetic flux after the magnetic force is removed is called ------.
   (c) Energy loss due to friction between molecules when forced into alinement by a magnetic force is called ------.
   (d) This energy loss produces ------ in the magnetic material.



CHAPTER 4

INDUCTION

ELECTRICITY FROM MAGNETISM

To produce an electric current a source of emf is necessary. The oldest and simplest known source of emf is the piling up of a static charge; that is, generating electric charges by friction and storing up these charges in a condenser. While it is possible to build up static charges to potentials of many thousand volts, these charges cannot be used to provide power for electric motors and the like because very little energy is stored up in static charges. Hence, they possess no reserve of energy to keep the electric current flowing, and once the spark has jumped the gap the potential falls to almost zero and the flow of electrons practically stops.

As you learned in *Basic Electricity*, static charges can also be created continuously by a number of different electrostatic machines, but the rate of building is too slow to make these machines of practical value as a source of emf.

For many years, primary cells were the only practical source of emf, but these were able to produce only small currents—currents strong enough to power only low-current

devices such as the telegraph and telephone. The electric motor, heating coils, and the hundred-and-one other heavy-current-consuming devices common today were not possible since batteries could not furnish the required amount of current.

All the modern electrical machines had to wait until a cheaper, more efficient, and larger source of emf was found. This came about when the principle of INDUCED ELECTROMOTIVE FORCES, or ELECTROMAGNETIC INDUCTION was discovered by Michael Faraday in 1831. Though the development of this principle of obtaining electricity from magnetism came about little more than 100 years ago, such rapid progress has since been made in designing better and larger generators based on this principle that now millions of kilowatts of electric power are delivered by these machines daily to homes and industry. And in the Navy generators based on the induction principle discovered by Faraday have been so far developed that those used in battleships and carriers could supply whole cities of moderate size with all the electric power necessary to run their factories, operate their street cars, and meet all the other electric power requirements of the community.

The story of how a generator does this starts with the following illustration.

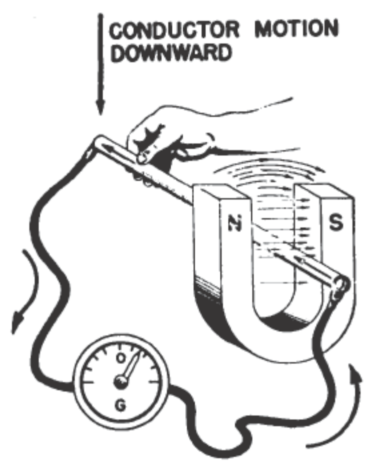


Figure 56.—An emf is produced when a conductor cuts a magnetic field.

In figure 56, a GALVANOMETER, an instrument that shows DIRECTION and AMOUNT of current, is connected to a con-

ductor. When the CONDUCTOR is moved DOWNWARD, into the field between the poles of a magnet, the galvanometer NEEDLE is DEFLECTED, indicating a current to be flowing in the conductor. The current produced flows in such a direction that the needle is deflected from the center of the scale TO THE RIGHT, as the figure shows. When the CON-

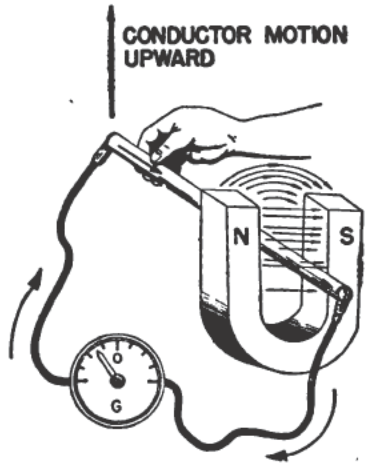


Figure 57.—Direction of induced emf depends on direction of cutting a magnetic field.

DUCTOR is moved UPWARD, out of the field, the NEEDLE *is* DEFLECTED in the OPPOSITE DIRECTION, indicating that the current has been reversed. When the CONDUCTOR is held MOTIONLESS, NO DEFLECTION is present; but MOVING the conductor QUICKLY through the field produces a LARGE DEFLECTION of the needle, and a SLOW MOVEMENT produces a SMALL DEFLECTION.

Here is what you have observed:

A downward movement of the conductor causes a deflection of the galvanometer in one direction.

An upward movement causes a deflection in the opposite direction.

The faster the movement, the greater the deflection.

No movement, no deflection.

You therefore conclude, as Faraday did when he discovered this phenomenon, that: MOVING A CONDUCTOR ACROSS A MAGNETIC FIELD GENERATES AN EMF which produces a current in the conductor; THE FASTER THE CONDUCTOR MOVES, THE GREATER THE EMF PRODUCED and therefore the greater the

current; and REVERSING THE DIRECTION OF MOVEMENT OF THE CONDUCTOR REVERSES THE EMF and therefore also reverses the current.

INDUCTION

The phenomenon of generating an emf and thus causing a current to flow in a conductor when it cuts across a magnetic field, as illustrated in figures 56 and 57, is called INDUCTION. Although in these illustrations the conductor moved and the field stood still, a VOLTAGE CAN ALSO BE INDUCED BY MOVING THE FIELD AND HOLDING THE CONDUCTOR STATIONARY. Thus, INDUCTION will take place whenever you have a MAGNETIC FIELD, a CONDUCTOR and a RELATIVE MOVEMENT exists between the two.

WHICH WAY AND HOW MUCH

There are two points about the phenomenon of induction that are of considerable importance to an electrician's mate. The first is, IN WHICH DIRECTION will the current flow? And the second is, HOW MUCH current will flow? The first can be answered using a simple hand rule, but the second requires the use of delicate measuring instruments.

HAND RULE FOR GENERATORS

The direction of the induced current depends on the direction of the magnetic field, and the direction of movement of the conductor relative to the field. Notice that this makes THREE "directions" involved in determining the direction of an induced current. They are—

The direction in which the CONDUCTOR *is* MOVING relative to the flux.

The direction of the flux FIELD.

The direction of the INDUCED EMF.

All three "directions" are inter-dependent, and are summed up in the GENERATOR HAND RULE. It states—

> Place the thumb, first, and middle fingers of the left hand all at right angles to each other as in figure 58. Then the FIRST FINGER points in the FLUX direction, the

THUMB points in the direction of the MOTION of the conductor, and the MIDDLE FINGER points in the direction of the INDUCED EMF.

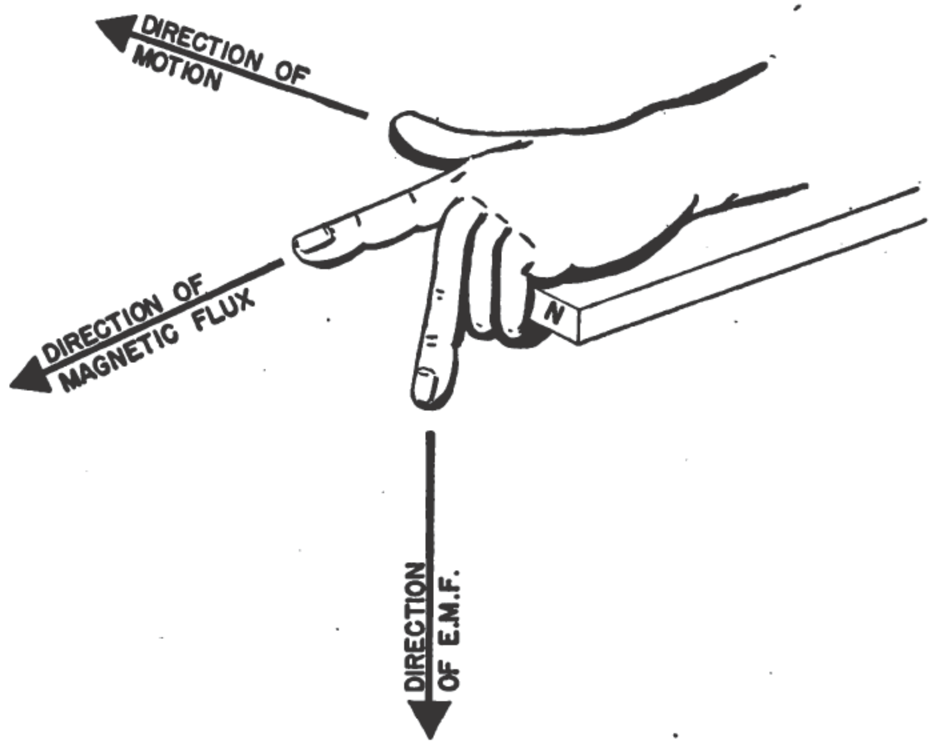


Figure 58.—The generator hand rule.

Figure 59 illustrates three examples of changing one of the directions. Note that the direction of emf changes every time either the direction of conductor motion, or direction of the magnetic field changes.

The generator hand rule will tell you the third "direction" anytime you know the other two. Sometimes it will be difficult to get your finger lined up with the known directions but just remember that it makes no difference whether you face the conductor, stand to one side of the conductor, or turn your back to the conductor. As long as your thumb points in the direction of motion, your first finger in the direction of the flux, then your middle finger must point in the direction of the induced emf. Stand on your head if you must—but get those fingers lined up! It might help you to construct a drawing like figure 60. Draw a circle for the cross-section of the conductor. Then run arrows out

in the direction of the flux and the motion. You can apply the generator hand rule directly to the diagram. Your middle finger tells you whether a dot (·) or a cross (+) goes in the cross-section of the wire.

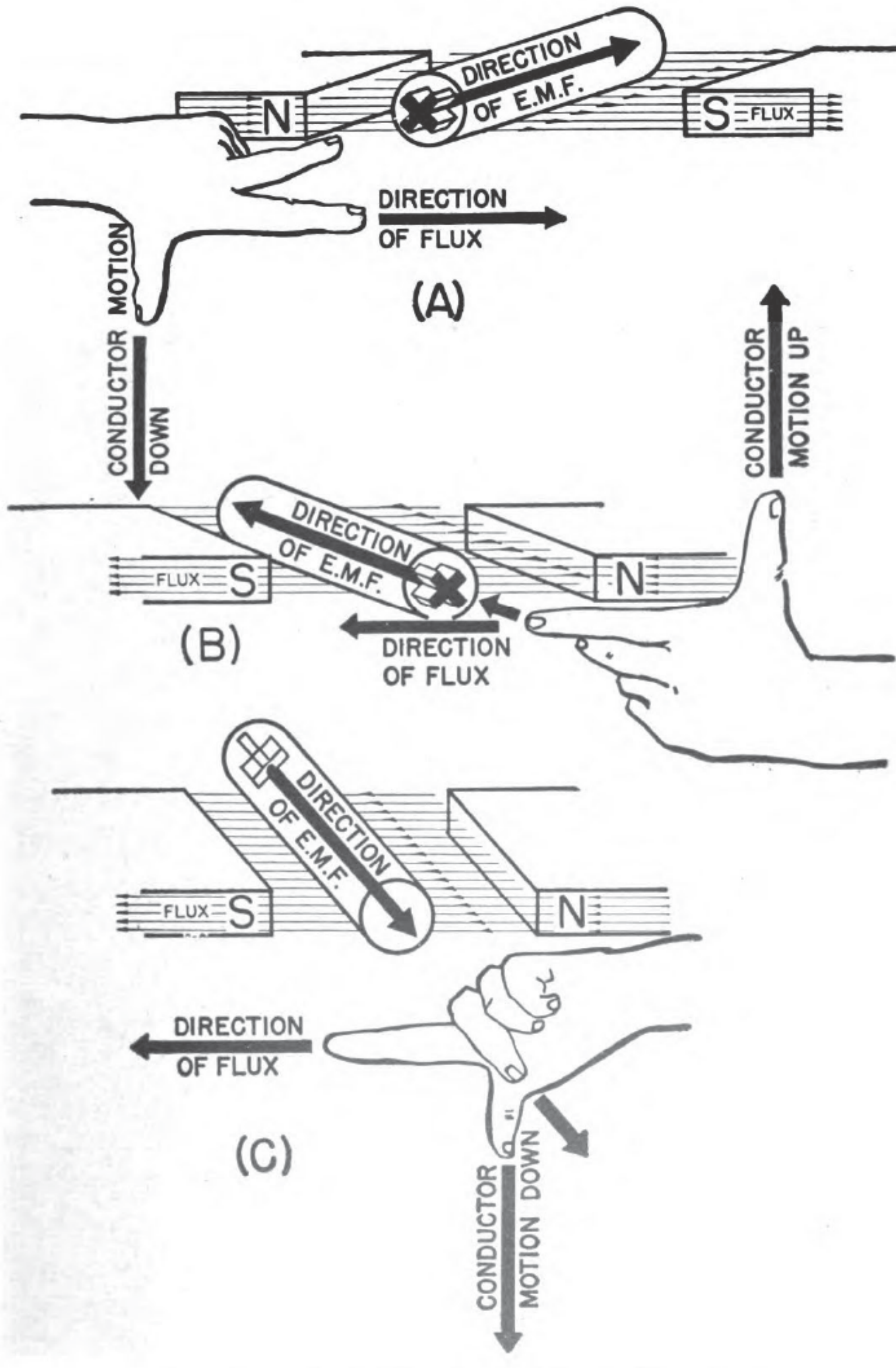


Figure 59.—Generator hand rule, examples.

The left hand rule is important because you will use it many times in your work on generators to determine the direction of the current. It can also be used to determine

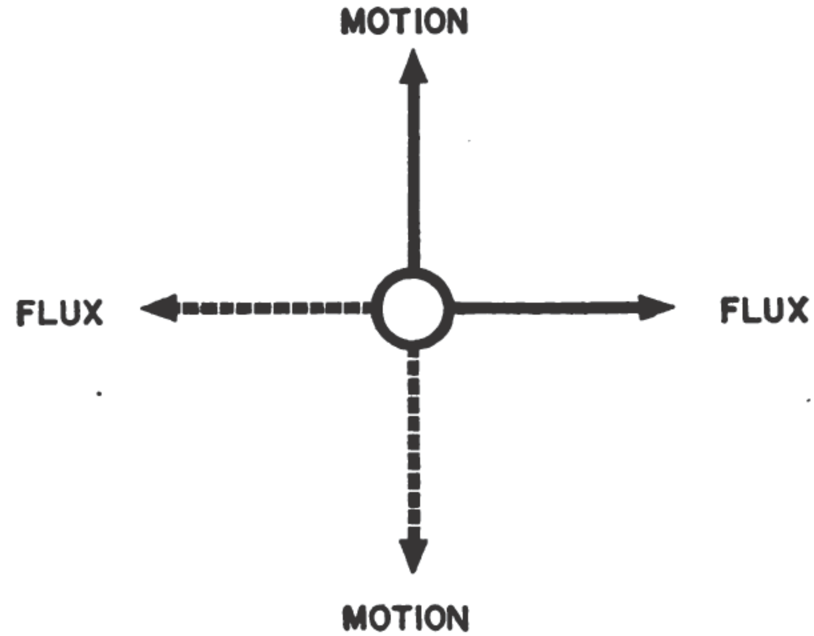


Figure 60.—Model for the generator hand rule.

the polarity of a generator field if you know the direction of the current and direction of rotation of the armature.

STRENGTH OF INDUCED EMF'S

You learned in an earlier paragraph that the faster the conductor moves across a magnetic field, the greater the induced emf. In moving across a magnetic field the conductor is cutting lines of force. So another way to say this is: THE MORE FLUX LINES A CONDUCTOR CUTS EACH SECOND THE GREATER IS THE INDUCED EMF.

It has been calculated that 100,000,000 LINES of flux must be CUT PER SECOND to PRODUCE ONE VOLT. Then 200,000,000 lines cut per second would produce 2 volts, etc. This is a lot of flux to cut in one second, so to make generators which produce appreciable voltages they must have powerful magnetic fields. The fields produced by permanent magnets are relatively weak, but with electromagnets enormously powerful fields can be produced. That is why the field magnets of all generators are electromagnets.

METHODS OF INCREASING INDUCED EMF'S

This principle, THE NUMBER OF FLUX LINES CUT PER SECOND, is the key to all the possible methods for increasing the voltage output of a generator. There are three: 1) cut the lines faster, by increasing the speed of movement of the conductor; 2) cut more lines with the same conductor, which means increasing the strength of the magnetic field; and 3) cut the lines with more than one conductor, which means making the conductor into a coil so that the field is cut by many lengths of the same conductor, instead of by a single length.

Method (1) is accomplished by increasing the speed of rotation of the generator. This explains the increased voltage output of an automobile or motor-launch generator when the engine is raced.

Method (2) is accomplished by increasing the ampere-turns of the electromagnet producing the field. This can be done either by increasing the field current, or by increasing the number of turns of the magnet coil.

Method (3) works because when a conductor is formed into a coil, each turn is in series with the other turns. Therefore, the voltage generated in each turn is added to the voltages generated in the other. Thus, suppose one conductor cutting a field produces 10 volts. This same conductor, coiled into 5 turns, and cutting the same field, will produce 50 volts.

MUTUAL INDUCTION

"Mutual" means that something is shared. MUTUAL INDUCTION means that two circuits share the energy of one. Strictly speaking, it means an electrical phenomenon in which energy is transferred from one circuit to another. How it is done is shown in figure 61. Coil A is the PRIMARY circuit and gets its energy from the battery. When the switch is closed the current starts to flow and a magnetic field expands out of coil A. Coil A thus changes the ELECTRICAL energy of the battery into the MAGNETIC energy of a magnetic field. When the field of coil A is expanding it

cuts across coil *B* (the SECONDARY circuit), inducing an emf in coil *B*. The galvanometer in circuit *B* is then deflected, indicating the current produced by the induced emf.

Here is an interesting fact—the induced voltage MIGHT have resulted from moving coil *B* through the flux of coil *A*. But the voltage was induced WITHOUT moving coil *B*. When the switch to *A* was open, *A* had no current and no field. But as soon as the switch was closed, current surged through the coil and a field blossomed out. This expanding field "moved" across the wires of coil *B*—thus lines of force were cut and a voltage was induced, WITHOUT MOVING COIL *B*.

In a small fraction of a second the field expands to its maximum strength and remains constant as long as the full current flows. "Moving" of flux lines across coil *B* stops

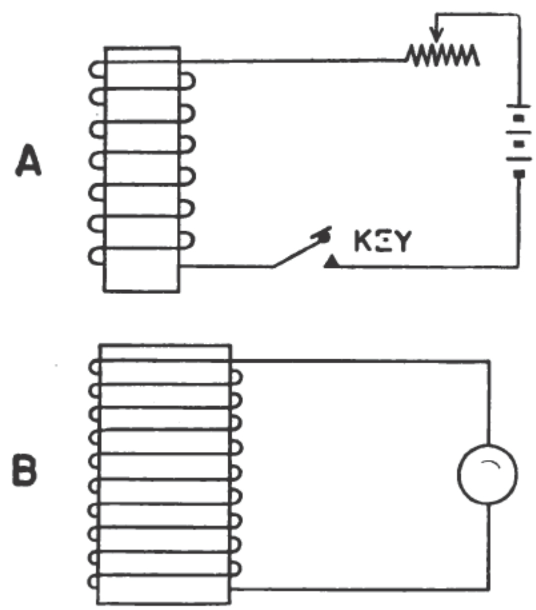


Figure 61.—Mutual induction circuits.

and induction ceases—as shown by galvanometer returning to zero. If the switch is opened, the field collapses back to the wires of coil *A*. Again the changing flux "moves" across the wires of coil *B*, but in the opposite direction. The galvanometer needle now deflects, but in the opposite direction, indicating that a voltage has again been induced, but in the reverse direction. The important point for you to see here is that INDUCTION OCCURS ONLY WHEN A FIELD IS CHANGING—either building up or collapsing, and that a

CHANGING FIELD PRODUCES INDUCED EMF'S EXACTLY AS A FIELD MOVING ACROSS A CONDUCTOR. This principle of generating induced voltage by holding the coils steady and forcing the field to change is used in a vast number of electrical devices. The spark coil in an automobile and the transformer are the most common.

You can always spot a MUTUAL INDUCTION set-up by its TWO circuits. One circuit—the primary—gets its energy from a voltage source (generator or battery) and the other circuit—the secondary—gets its energy by induction from the field of the primary.

In summary, there are then two methods of generating INDUCED emf's:

When lines of force are cut by a conductor, due to movement of the field or the conductor. This is the principle underlying all generators.

When the current in a primary circuit changes, and its flux lines cut across the conductors of the secondary. This principle underlies all transformers, induction coils, etc.

LENZ'S LAW

The principle that a conductor carrying a current is surrounded by a magnetic field holds true for currents resulting from induced emf's as well as for currents from any other source. To illustrate this, look at the four drawings in

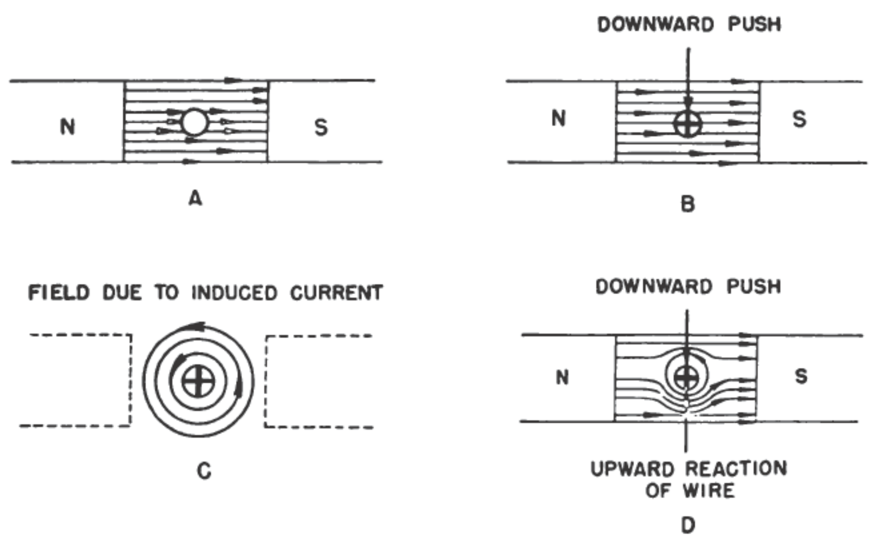


Figure 62.—Lenz's law.

figure 62. The first diagram, *A*, shows a conductor at rest in a stationary magnetic field. Being stationary, the conductor has no induced emf and no current. The second diagram, *B*, shows the conductor being pushed downward. Note that two items have been added—the downward push and the resulting induced current in the conductor. Since a magnetic field surrounds every conductor carrying current, the conductor will have a field of its own due to the induced current, and the generator hand rule tells you that this field will be in a counter-clockwise direction, as shown in the third diagram, *C*. There are now TWO fields surrounding the conductor—the one from the MAGNET and the one from the induced CURRENT in the conductor. The first is a straight line field travelling from the North pole to the South pole. The second is a circular field surrounding the conductor.

Because magnetic lines never cross, the lines of these two fields must either CROWD TOGETHER producing a STRONG resultant field, or they must CANCEL, producing a WEAK resultant field. *A* of figure 63 shows what happens ABOVE the wire. The two magnetic fields meet head-on and CANCEL each other. The cancellation of flux lines results in a WEAK field ABOVE the conductor.

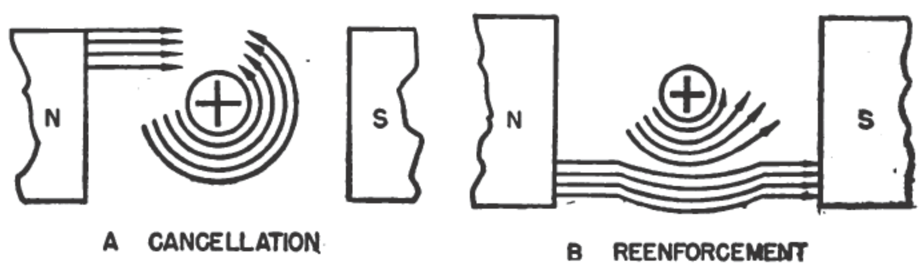


Figure 63.—Lenz's law—action between conductor and magnetic fields.

B of figure 63 shows that BELOW the wire the two magnetic fields are in the same direction, so their fluxes ADD. This addition of flux lines results in a STRONG field BELOW the conductor.

Thus as a result of the induced current, the magnet field is distorted by the field around the conductor, resulting in a weak field above and a strong field below the conductor. Now remember that flux lines tend to push each other apart.

Therefore, as you can see in figure 62D, the flux LINES BELOW the conductor, pushing each other apart, tend to PUSH the conductor UP, while the LINES ABOVE the conductor tend to PUSH it DOWN. But there are more flux lines below the conductor, so the upward push is greater, and the conductor has a magnetic force tending to move it up. All these conditions are summed up in *D* of figure 62. Better review them. Refering to figures 62 and 63, you observe—

The DISTORTED FIELD resulting from the combination of the straight field of the poles and the circular field of the induced current in the conductor.

The DOWNWARD FORCE applied by a push on the conductor.

The UPWARD FORCE which results from the distorted field.

These facts tell you that whenever you apply a push to move a conductor across a magnetic field, there is induced a current which sets up a field that tries to move the conductor back against the push. This is Lenz's law: IN ALL CASES OF ELECTROMAGNETIC INDUCTION, THE DIRECTION OF THE INDUCED EMF IS SUCH THAT THE MAGNETIC FIELD SET UP BY THE RESULTING CURRENT TENDS TO STOP THE MOTION WHICH IS PRODUCING THE EMF.

LENZ'S LAW AND THE OPERATION OF GENERATORS

Let's look into this action a little further. Suppose you try to push a conductor DOWNWARD through a magnetic field. Immediately the induced current sets up a field that tries to push the conductor UPWARD (Fig. 62D). The force you use in the DOWNWARD push is bucked by the magnetic UPWARD push. If you push harder, the conductor goes faster, cuts magnetic lines faster, and so has a higher induced emf. But this only produces more induced current and a stronger conductor field. Consequently, a stronger UPWARD force is automatically produced to buck the stronger DOWNWARD force.

So, if you push a conductor faster across a magnetic field to produce more electrical output, you have to push harder on the conductor. Practically this means that, to get more electrical output from a generator, you have to use more

power to drive the generator. For example, if the generator is driven by a steam engine, you must increase the steam flow to increase the generator output.

Here's another example. Have you ever heard a motor-driven welding generator? When the welding arc is struck the driving motor whines and labors. Lenz's law is working. The arc increased the generator's current output and the driving motor is working against the increased opposing force which was set up by this increased current. The motor must increase its input to balance the increased output for the arc.

SELF INDUCTION

There are only three items required to generate an induced voltage—a conductor, a magnetic field, and moving or changing flux lines of this field cutting across the conductor. These three items give you LINES OF FORCE CUT BY A CONDUCTOR. Look at figure 64. Are these three items present in this circuit?

Conductors?—the coil has plenty of them.

Magnetic field?—the coil sets it up whenever current flows.

Flux lines cutting the conductor?—occurs only when the field is changing.

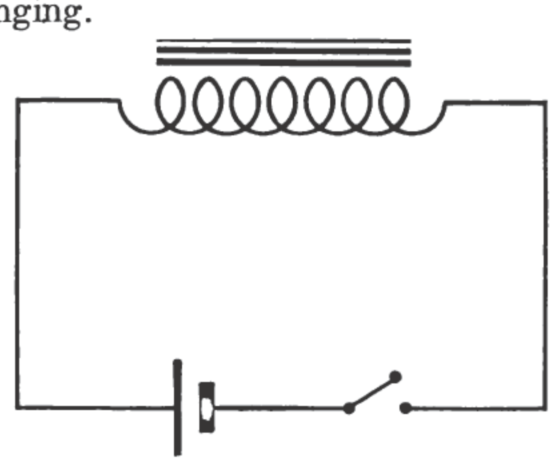


Figure 64.—Self-induction circuit.

To make the field change, all you have to do is open and close the switch. This kind of induction is called SELF-INDUCTION, and here is how it works: At the instant the switch is closed the current starts and magnetic lines expand from the center of each conductor. As these lines blossom

outward, they cut across the other conductors of the coil. An emf is induced in each conductor cut by the flux.

Figure 65 shows an enlargement of only two turns of the coil in figure 64. Flux is pictured blossoming out from one of the turns. Notice how these lines cut the next turn.

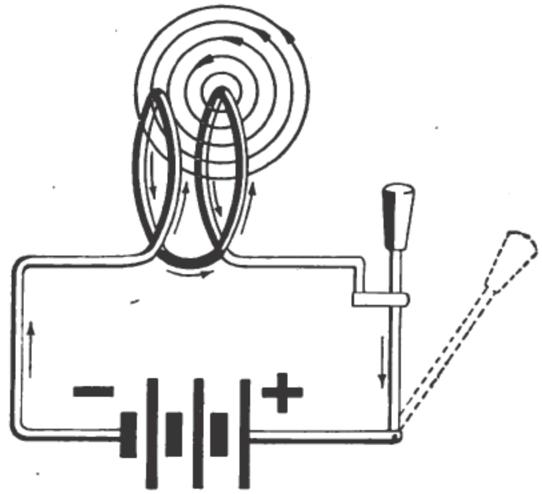


Figure 65.—Self-induction in one turn.

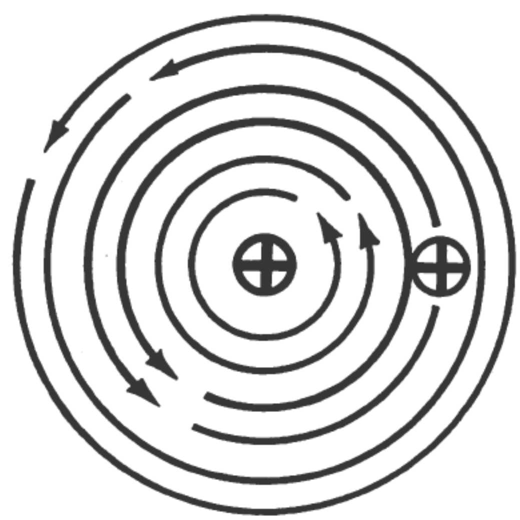


Figure 66.—Self-induction fields around conductors.

Now, applying the generator hand rule, determine the direction of the induced voltage in the second turn. It's easier to use the rule on a cross-section of the coil as in figure 66. Flux direction is down (first finger). Motion is to the right (thumb). (Attention—the flux is moving across the con-

ductor to the left—the effect is the same as though the conductor were moving to the right.) Induced voltage (middle finger) is in a direction out of the paper. But the battery voltage is producing current flow in. Hence that is exactly what happens. THE INDUCED VOLTAGE OPPOSES THE FLOW OF CURRENT.

What happens when the switch is opened? The field collapses and cuts across the conductor in the opposite direction. Because the direction of motion has reversed, the induced emf is now IN. Thus, IN A COLLAPSING FIELD, THE INDUCED EMF AIDS THE FLOW OF CURRENT.

These are the characteristics of self-induction—

Any coil will INDUCE a VOLTAGE in itself WHENEVER its CURRENT value CHANGES.

When the CURRENT is INCREASING (field expanding), the INDUCED EMF OPPOSES CURRENT FLOW.

When the CURRENT IS DECREASING (field contracting), the INDUCED EMF AIDS the CURRENT flow.

This is in effect, just another case of Lenz's law. Only in place of the force moving the conductor you have the applied voltage from the battery, and in place of the bucking force you have the self-induced voltage. Hence for self-induction, Lenz's law states: the induced voltage OPPOSES the applied voltage when the current is INCREASING and AIDS the applied voltage when the current is DECREASING. Or, in self-induction the INDUCED VOLTAGE OPPOSES ANY CHANGES IN THE CURRENT value.

SELF-INDUCTION—THE HARM IN IT

The voltage of self induction can be very troublesome. Imagine that you are operating the switch controlling the field coils on a large motor. These coils have thousands of turns. When the switch is closed, the voltage of self induction does little damage. It opposes the increase of current flow for an instant (perhaps 0.1 second), but as soon as the field is built up and stationary, the induced voltage ceases. On the other hand, when the switch is opened, the field rapidly contracts. The induced voltage on collapse may be hundreds of times as strong as the applied voltage. This tre-

mendous induced voltage drives current across the opening switch terminals in the form of an arc—it CAN burn both the operator and the switch very badly. All switches subject to high induced voltages are protected by discharge resistors to absorb and dissipate the induced voltage, which might otherwise cause dangerous arcs.

SELF INDUCTION—THE GOOD IN IT

The voltage of self-induction can also be very useful. Imagine that you close the switch to energize the sucking coil of a relay. The instant the switch is closed the current starts to rush in, but this produces a large bucking voltage of self-induction which largely cancels the applied voltage, E. Very little voltage is therefore left to force current through the circuit, and so only a small current flows through the relay coil immediately after the switch is closed.

As the voltage of self-induction dies down, the voltage applied to the coil circuit comes up to the full applied voltage, E, and the current builds up GRADUALLY to the full value given by $I=E/R$. Since the sucking coil will not pull in the iron core until nearly the full $I=E/R$ current is flowing, there is a TIME DELAY between the closing of the circuit of the relay coil and the pull-in of the relay core. The greater the coil's inductance, the greater this time delay.

Time delays are necessary between the opening and closing of different circuits for motor starting, for motor stopping, and for the safe operation of much other electrical equipment aboard ship. You will therefore run across time delay relays in nearly all the electrical euqipment you work on. Remember, the time delay depends on the inductance of the relay coil; so if you have to replace the coil of one of these relays, BE SURE THE REPLACEMENT COIL HAS THE RIGHT INDUCTANCE to produce the required time delay.

NONINDUCTIVE COILS

Some electrical circuits require NONINDUCTIVE coils for proper operation. You say how come? How is it possible to have a noninductive coil since all conductors carrying a current are surrounded by magnetic fields? Look at figure 67.

The wire used to wind the coil is DOUBLED BACK, as illustrated in diagram *A*, so the starting end of the conductor is next to the finishing end. The current flows from left to right in the upper wire but returns in the OPPOSITE direction

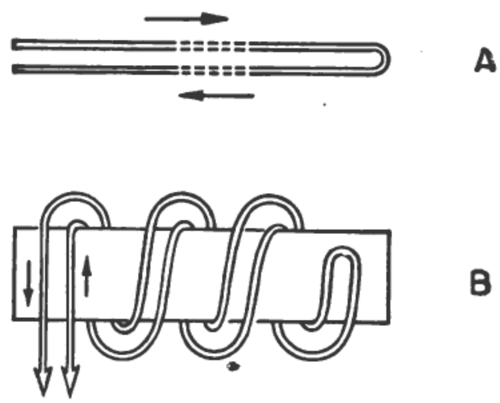


Figure 67.—Noninductive coil.

in the lower wire, therefore the MAGNETIC FIELDS in the two wires will be OPPOSITE and CANCEL each other.

When the DOUBLED conductor is wound about a core as illustrated in figure 67B, the magnetic fields cancel each other, resulting in a noninductive coil.

EDDY CURRENTS

A solid piece of metal usually is not thought of as a conductor in the same sense as the word "conductor" is used with electrical circuits, but if a solid piece of metal moves through a magnetic field it too will have an emf induced in it.

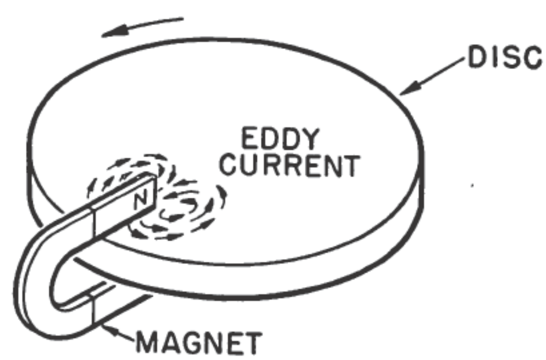


Figure 68.—Eddy currents in a disk.

In figure 68 the edge of a metal disk is placed between the poles of a horseshoe magnet. As long as the disk is motionless,

no emf will be induced, but any motion by either the magnet or the disk will result in flux lines being cut by a conductor and so will cause a small current to circulate within the metal. Since these currents have random movements and follow irregular paths they are called EDDY CURRENTS.

Eddy currents obey all the usual laws of induction. The most evident is the OPPOSITION TO MOVEMENT according to Lenz's law. As an example, if the disc in figure 68 is being continuously rotated, the eddy curents will cause a DRAG and tend to slow down the rotation of the disc.

Large, thick pieces of metals have stronger eddy currents than thin, small sections, because the larger cross sections offer less resistance to the induced emf. Electrical devices like generators and motors where large quantities of iron rotate in magnetic fields have their iron cores made of many small thin sections or LAMINATIONS bolted together, rather than one large solid casting. The laminations do not PREVENT eddy currents. they merely REDUCE them, because they

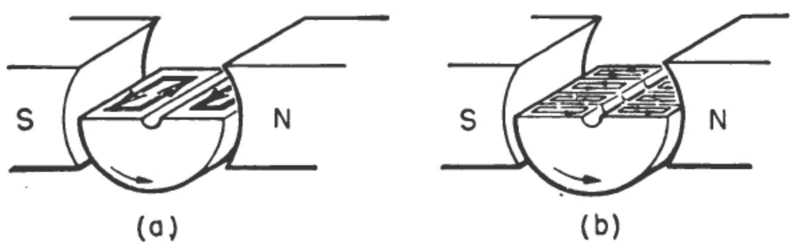


Figure 69.—Effect of laminations on eddy currents.

increase the resistance of the eddy current path. The effect of lamination is illustrated in figure 69. Notice the difference in the size of eddy currents in the two diagrams.

Eddy currents, like all other currents, produce heating. Heating of the iron cores of electrical motors and generators only wastes energy and damages the insulation of the winding. It is therefore very important that the cores of electrical machines be laminated, to reduce the eddy currents and therefore their heating effects.

Some electrical instruments such as sensitive voltmeters and ammeters use solid iron cores to INCREASE the effect of eddy currents. This is done to produce a DAMPING EFFECT

or drag, that causes the needle to come to rest QUICKLY after energy has been applied to the meter. Without this DAMPING action, the meter needle would swing back and forth for many minutes thus making the task of obtaining meter readings slow and tedious.

QUIZ

1. Who discovered electromagnetic induction?
2. Complete the following statements:
   (a) The principle of electromagnetic induction states that when a conductor is moved across a magnetic field an electromotive force (emf) is ------ in the conductor.
   (b) Faraday found that when a conductor is moved across a magnetic field
      (1) The faster the conductor moves the ------ the emf.
      (2) Reversing the movement of the conductor ------ the emf.
      (3) If the conductor is stationary the emf is ------.
   (c) Whenever there is relative ------ between a conductor and a magnetic field induction takes place.
3. Complete the following:
   (a) To indicate the direction of induced emf hold the left hand so that
      (1) The first finger points in the direction of ------.
      (2) The thumb points in the direction of ------.
      (3) the middle finger will point in the direction of ------.
   (b) To reverse the direction of the induced emf you must reverse the direction of either
      (1) conductor ------ or
      (2) magnetic ------.
   (c) The left hand rule for direction of induced emf will help you determine the direction of ------ produced in a generator.

4. Complete the following statements:
   (a) The more flux lines a conductor cuts each second the ------ is the induced emf.
   (b) 100,000,000 flux lines must be cut by a single conductor each second to produce one ------.
   (c) To cut more lines per second you must
      (1) increase the ------ of the conductor.
      (2) increase the strength of the ------.
      (3) use more ------ in each coil of the armature.
5. Complete the following statements:
   (a) A voltage is induced in a conductor when the magnetic field around it is ------.
   (b) When a voltage is induced in one circuit by change of current in another.
      (1) the circuit in which the current is changing is called the ------.
      (2) The circuit in which the voltage is induced is called the ------.
   (c) Production of an emf in one circuit by change of current in another is called mutual ------.
   (d) The circuit in which the current is changing gets its energy from a battery or ------.
   (e) The circuit in which a voltage is induced gets its energy from the ------ of the other circuit.
   (f) Induction by movement of a conductor underlies the operation of ------.
   (g) Induction by flux linkage of one circuit to another underlies the operation of ------.
6. Complete the following statements:
   (a) An induced current, like the current produced by a battery, creates a magnetic------ around the conductor.
7. You know from Faraday's laws that:
   (1) When you move a conductor across a magnetic field you generate an induced emf in the conductor.
   (2) The induced emf sets up an induced current in the conductor.
   (3) The induced current sets up a magnetic field around the conductor.

Using this information complete the following statements:

(a) Lenz's law states that this magnetic field will be in a direction to ______ the conductor motion that is creating the induced emf.

(b) Lenz's law means that the more power output you get from a generator, the ______ the prime mover must work to drive it.

8. Complete the following statements:

(a) Flux produced by one turn of a current-carrying coil, cutting another turn, produces a voltage of ______ induction.

(b) Any coil carrying a current will induce a voltage in itself whenever its current ______.

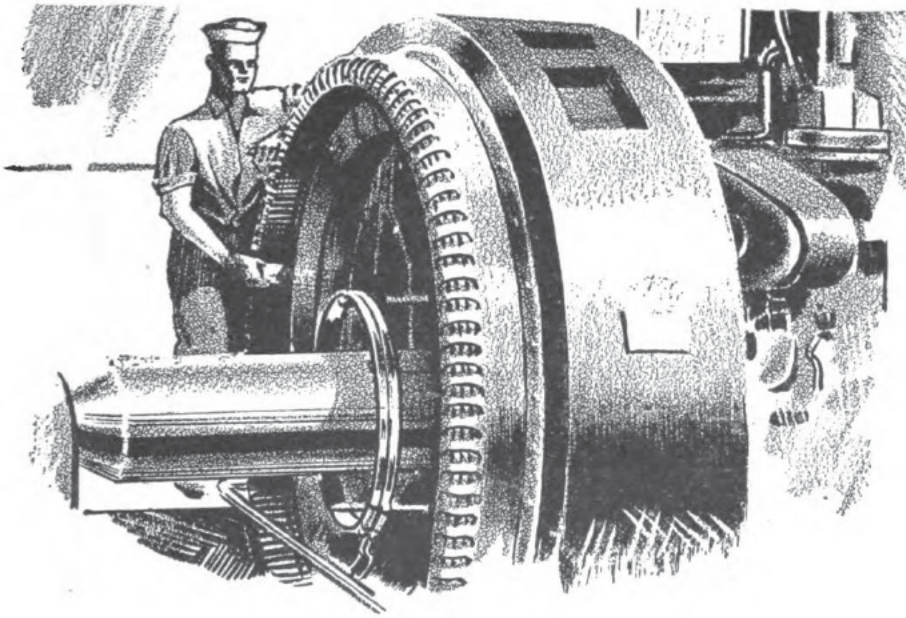
(c) When the current is increasing, this induced emf will ______ the current flow.

(d) When the current is decreasing this induced emf will ______ the current flow.

(e) In self induction the induced emf ______ any changes in the current value.

9. The self induced voltage in a generator field helps current flow across the switch in the field circuit when this switch is ______.

10. Resistors are connected across the switch for the field circuit of a generator to prevent burning of the switch when it is ______.



CHAPTER 5

ALTERNATING- AND DIRECT-CURRENT GENERATORS

FROM MECHANICAL POWER INTO ELECTRICITY

The ALTERNATING CURRENT GENERATOR is a relatively simple machine with just four major parts, stator, armature, slip rings and brushes.

In figure 70, which shows a schematic arrangement of an a-c generator, the STATOR is a permanent magnet placed in such a position that the strongest field is between the two poles. The ARMATURE is a loop of wire placed in the magnetic field so that turning the loop will rotate it in the flux. The SLIP RINGS are two complete copper rings. Note that the BLACK ring is attached to the BLACK leg of the loop, and the WHITE ring to the WHITE leg of the loop.

Both the LOOP and the SLIP RINGS are mounted on a SHAFT, and the mechanical power is applied to the shaft. The BRUSHES are pieces of carbon held stationary against the slip rings by the generator framework.

The GALVANOMETER in figure 70 is not a part of the

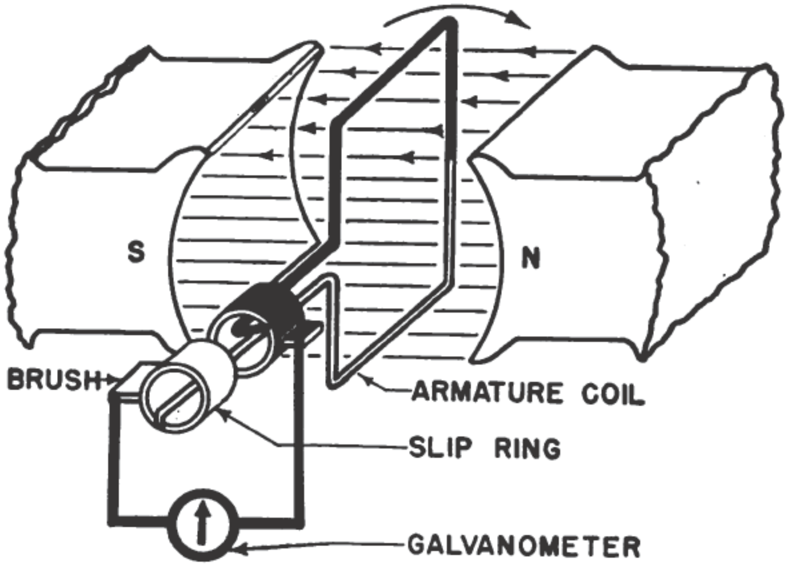


Figure 70.—Parts of a generator.

generator, but is added to the drawing to indicate the direction of the current.

OPERATION OF A GENERATOR

Here is how the generator works. In figure 71 the loop is rotating in a clockwise direction. In drawing *A*, the BLACK leg is moving toward the north pole, and the WHITE leg toward the south. Thus both legs are moving PARALLEL to the lines of flux, and not CUTTING ACROSS any. Since no flux is cut, no voltage is induced, and the galvanometer needle stands at zero.

The loop, in position *B*, has rotated ¼ of a turn. The black leg is moving downward, and the white up. In this position, both legs are CUTTING across a MAXIMUM number of lines of FLUX, and the EMF, as indicated by the galvanometer, is MAXIMUM.

When the loop arrives at position *C*, ½ of a rotation has been made. The two legs are once more moving PARALLEL to the lines of FLUX, and the galvanometer stands at zero.

In the last drawing, *D*, the black leg is moving upward, and the white one downward. Both legs again are cutting a maximum number of lines of force, but in the OPPOSITE direction to that in position *B*. Since the legs are CUTTING

the FIELD in the OPPOSITE direction, the emf induced will be opposite and will cause the CURRENT to FLOW in the OPPOSITE DIRECTION.

The next ¼ rotation brings the loop back to the same position as in *A*, and the procedure starts over again.

Now go back and review what happened during one rotation. The emf started at ZERO, increased to a MAXIMUM value in ONE DIRECTION, fell back to ZERO, then increased to MAXIMUM in the OPPOSITE DIRECTION, then finally returned to ZERO.

Look at figure 72. It shows what happens in the loop of figure 71 in 5 positions. Below the loops is a graph of the induced emf. Line *A*-*E* is the zero line. All the area above this line is indicated as being positive (+) and the area below as minus (−).

In position 1 (drawing A, fig. 71), the loop is cutting no lines of force, so the induced emf is zero—point *A*. One quarter rotation later, the loop is in position 2. It is cutting a maximum number of lines of force, so the emf is maximum, at point *B*. At position 3, the loop has completed ½ a rotation, and no lines of flux are being cut, so the emf is back to zero, at point *C*. In position 4, the loop is cutting

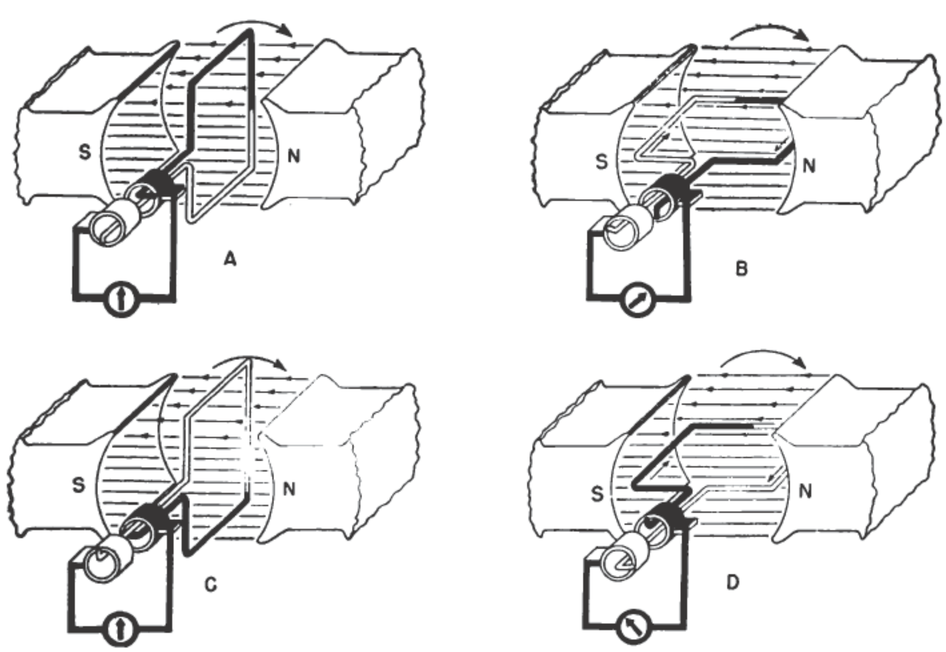


Figure 71.—Generation of an alternating emf.

the field in the direction opposite to that in position 2. The voltage induced in the coil is maximum, but in the opposite direction, point *D*. Position 5 is the same as 1, so the loop is ready to start over again.

WHAT IS AN ALTERNATING EMF?

The emf produced by the generator in figure 72 is an alternating emf. It starts at zero, rises to maximum in one direction (+), falls back to zero, rises to maximum in the

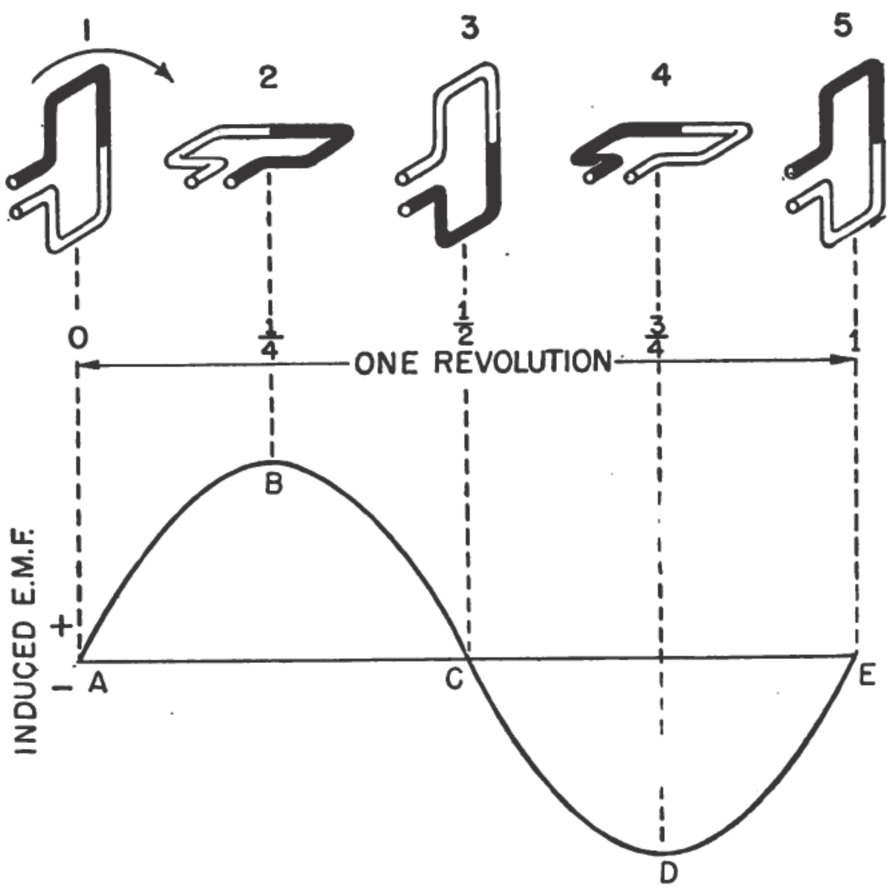


Figure 72.—An alternating emf.

opposite direction (—), and then comes back to zero. An alternating emf causes the current to flow first in one direction and then in the other, hence the name, ALTERNATING current or just plain a-c.

Notice in particular that an alternating emf is on BOTH sides of the zero line. If the emf is all on ONE side of the zero line, whether all negative or all positive, it is DIRECT current.

THE SINE WAVE

Suppose you rotate a wheel at uniform speed and watch the outer end of one spoke. As the wheel goes around, the end of the spoke will vary in height above the horizontal diameter of the wheel, as shown in figure 73. This curve,

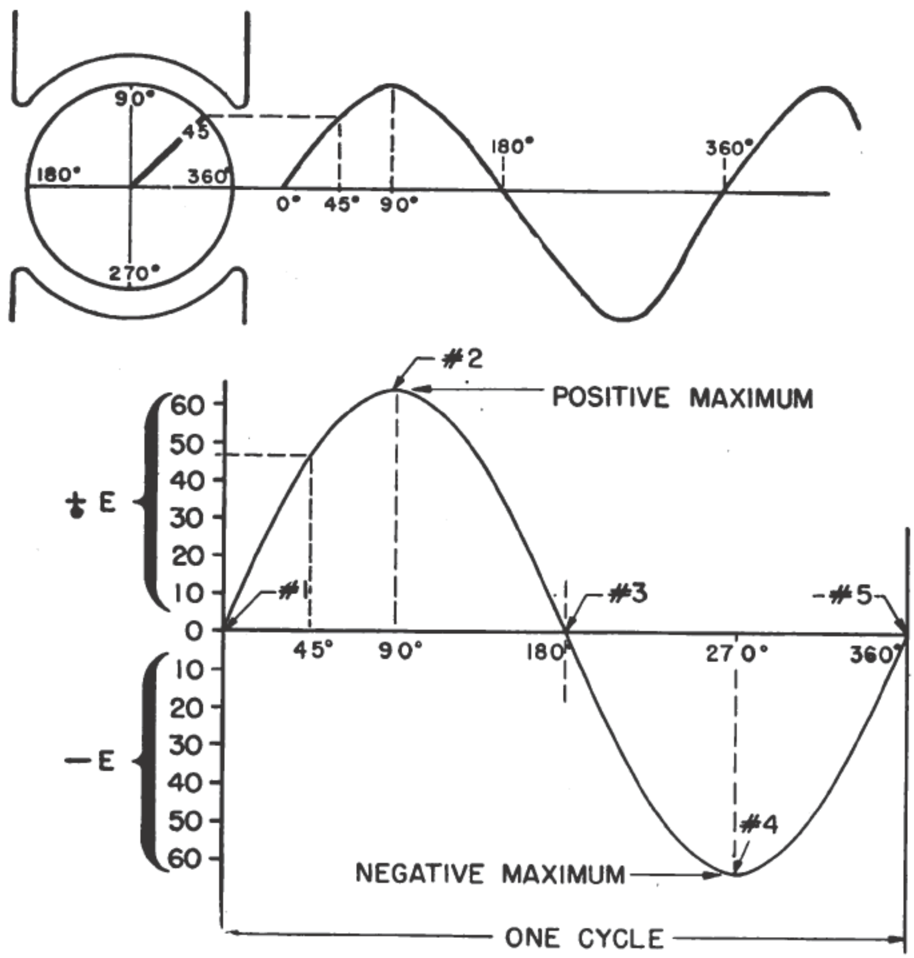


Figure 73.—A sine wave graph of a. c.

showing the height of a point on the rim of a wheel above the horizontal diameter as the wheel goes around, is used very much in mathematics and is called a SINE WAVE.

The emf produced by the generator in figures 71 and 72 does not change abruptly from zero to maximum, but fol-

ows this sine wave curve. It isn't necessary that you understand the mathematics of the sine wave, but you should be able to recognize it, and know something about its structure.

In figure 73, point number 1 is the same as point 1 in figure 72. Ninety degrees of rotation later, the loop is in position 2, and the voltage is maximum positive. The voltage generated by the first quarter rotation of the loop is included in the curve between points 1 and 2. Directly below point 2, and on the zero line, the number 90° is written. The portion of the base line between 0° and the 90° includes the angular rotation of the first ¼ of a revolution.

Now if you wish to know the emf generated after 45° of rotation, draw a vertical line from the 45° point on the base line (half way between 0 and 90), upward until it cuts the curve at point *A*. Draw a horizontal line from point *A* over to the scale to the left, and you will find it to be about 47 volts, that is if 60 volts is the maximum emf.

After the first 90°, the emf begins to fall. It continues until it is back to "zero," 180° later. The loop has now completed ½ a revolution. 270° after the start of rotation the voltage is again maximum but in a negative direction. Beyond point 4 the voltage again falls to zero as the loop returns to its starting point.

The next time around, the loop will generate the same emf, and so on for each rotation. A complete rotation is called a cycle, and each rotation thereafter is another cycle.

Thus, if 10 complete sine waves are made in 1 second, the frequency of the emf is 10 cycles per second. Similarly, 60 sine waves a second is a frequency of 60 cycles a second.

Sixty cycles per second is the frequency of the alternating current used with commercial electricity power systems, and you will find it used most frequently in the Navy.

THE LEFT-HAND RULE AND THE GENERATOR

Turn back to figure 71 again and apply the left-hand rule for generators to check whether the indicated direction of current flow is correct. Remember your thumb points the direction of motion, the index finger the direction of flux, and your other fingers the direction of current. By apply-

ing the left-hand rule to both legs of the loop, you can prove to yourself that the current always flows in one direction when the leg of the conductor is in front of the south pole, and in the opposite direction when it is in front of the north pole.

FIELD MAGNETS

A few small generators use permanent magnets to provide the magnetic field, but the number of cases where this is true will be so low that you can forget about them. In generators, as in other cases, an electromagnet instead of a permanent magnet is used to obtain a stronger magnetic field.

The source of emf to excite the field in figure 74 is shown as a battery, but with large Navy generators it is more practical to use a direct current generator to supply the emf. In most a-c generators the field magnets are mounted on the shaft and rotate between armature coils fixed to the stator.

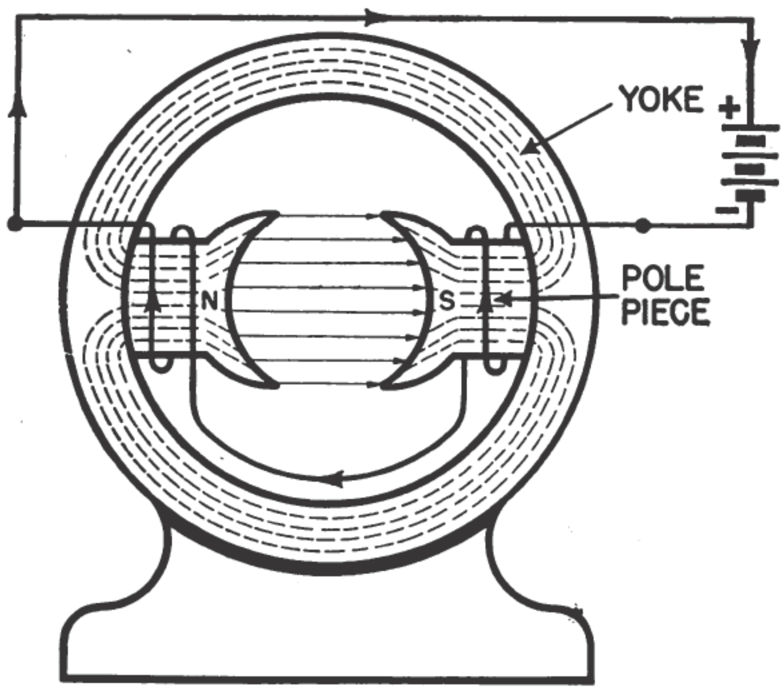


Figure 74.—Alternating current generator-electromagnetic stator.

ARMATURE

The armatures used with actual generators have many turns of wire instead of a single loop. The wire is wound

on a core made of SHEETS of SOFT IRON, tightly clamped together. The iron core is attached to the shaft, and the shaft in turn is driven by a pulley and drive belt. More about generator armatures is found in the following chapters.

PARTS OF A DIRECT CURRENT GENERATOR

By making a slight change in the slip rings of an a-c generator, you can obtain a direct current from a generator instead of an alternating current. In figure 75, the two slip rings of figure 70 have been changed to a SINGLE, TWO-

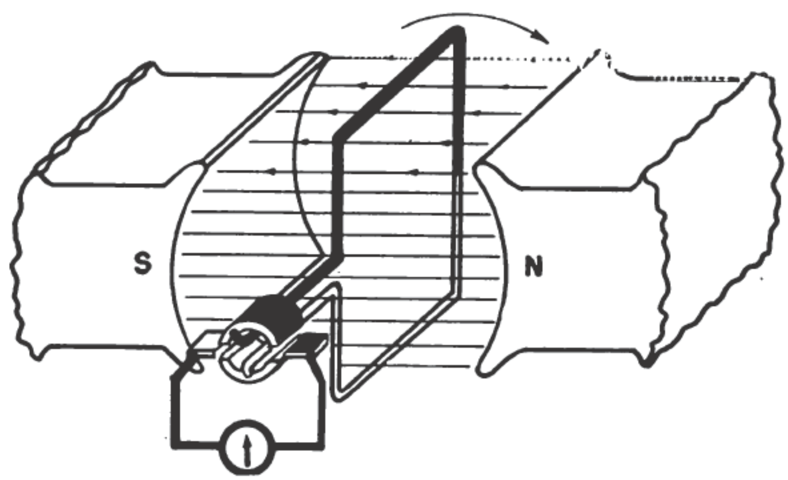


Figure 75.—Parts of a direct current generator.

SEGMENT RING. The BLACK LEG of the loop is connected to the BLACK SEGMENT, and the white leg to the WHITE SEGMENT. The two segments are insulated from each other, so no electrical contact is present between segments, the shaft, or any other part of the armature. This SPLIT RING is known as the COMMUTATOR.

Notice how the two BRUSHES are on opposite SIDES of the SPLIT RING and are mounted in a manner that permits each brush to be in contact with each segment as the armature turns.

HOW A DIRECT CURRENT GENERATOR WORKS— THE PRINCIPLE OF COMMUTATION

The generation of the emf by the loop cutting across the magnetic field is the same in a d-c as it is in the a-c gen-

erator, but the changing of a-c to d-c takes place at the COMMUTATOR.

The loop in position *A* of figure 76 is moving in a clockwise direction, parallel to the flux, hence no emf is generated. See also figure 71. Notice that the black brush is just coming in contact with the black segment, and the white brush with the white segment.

In position *B*, the flux is being cut at a maximum rate, so maximum emf is induced. The black brush is contacting the black segment and the white brush and the white segment, and the galvanometer needle is deflected to the right. At position *C*, the loop has completed 180° of rotation. No flux is being cut, so the emf, as indicated by the galvanometer, is zero.

The important condition to observe in position *C* is the action of the segments and brushes. The black brush is slipping off the black segment and onto the white, while at

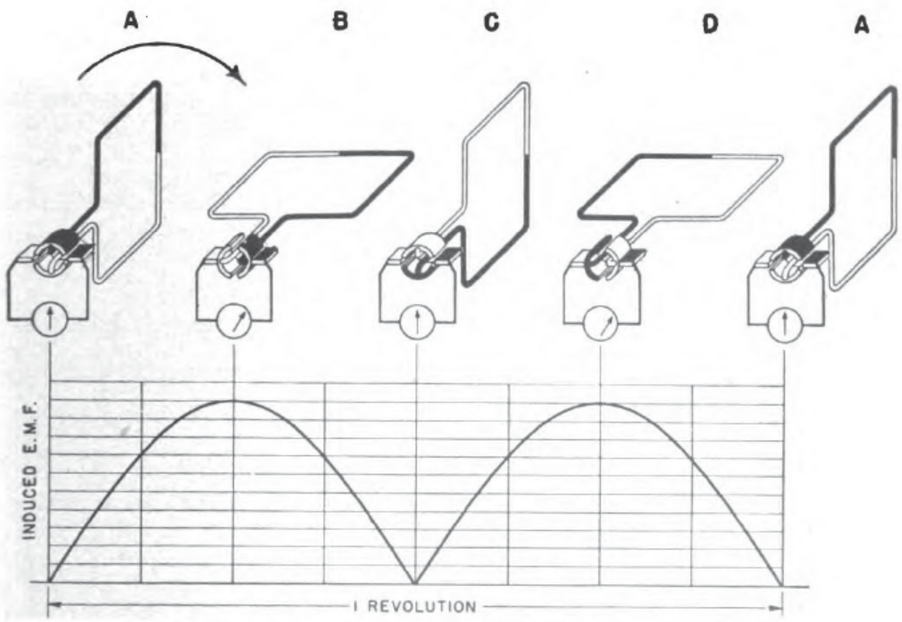


Figure 76.—Operation of a d–c generator.

the same instant the white brush is leaving the white, and moving onto the black.

This switching of commutator segments also switches the legs of the loop. In this way the BLACK BRUSH is ALWAYS IN CONTACT WITH THE LEG MOVING DOWNWARD, and the

WHITE BRUSH IS ALWAYS IN CONTACT WITH THE LEG MOVING UPWARD. Though the current actually reversed itself in the loop, it is always flowing in the same direction through the galvanometer. This switching action has the same effect as if you switch leads on the generator legs every 180° of rotation. Since manual switching of the leads several hundred times a second is impossible, the commutator and brushes solve the problem for you automatically

A graph for one cycle of a d-c generator is given in the lower part of figure 76. The generation of the emf for positions *A*, *B*, and *C* is the same as for an a-c generator, but at position *C*, the brushes in moving from one segment to the other causes the current in the external circuit to flow in the positive direction rather than becoming negative. Hence you will sometimes hear the process of commutation called RECTIFICATION—meaning to straighten out. The current within the loop continues reversing its direction each 180° of rotation, but the combined action of the commutator and brushes causes the current in the external circuit to flow in one direction only.

COMMUTATION PROBLEMS

During the instant the brush slips from the commutator segment to the other, the brushes and segments form a direct short circuit. If there is an emf present at that instant, it will cause a high current to flow in this short circuit, causing an arc and thus damaging the commutator. For that reason, the brushes must be placed in the exact position where the emf is zero. This position is called the NEUTRAL PLANE. Later in this Course, the problem of commutator sparking will be discussed more fully.

GENERATOR RIPPLE

The direct current furnished by a single loop armature is very bumpy, or pulsating, as you see from the graph in figure 76. It starts at zero, rises to maximum, and falls back to zero TWICE for each rotation of the loop. To produce a smoother direct current, more loops of wire are added to the armature.

In figure 77, two coils are used instead of one. There are now four segments in the commutator but only two brushes. With this arrangement, the voltage cannot fall any lower

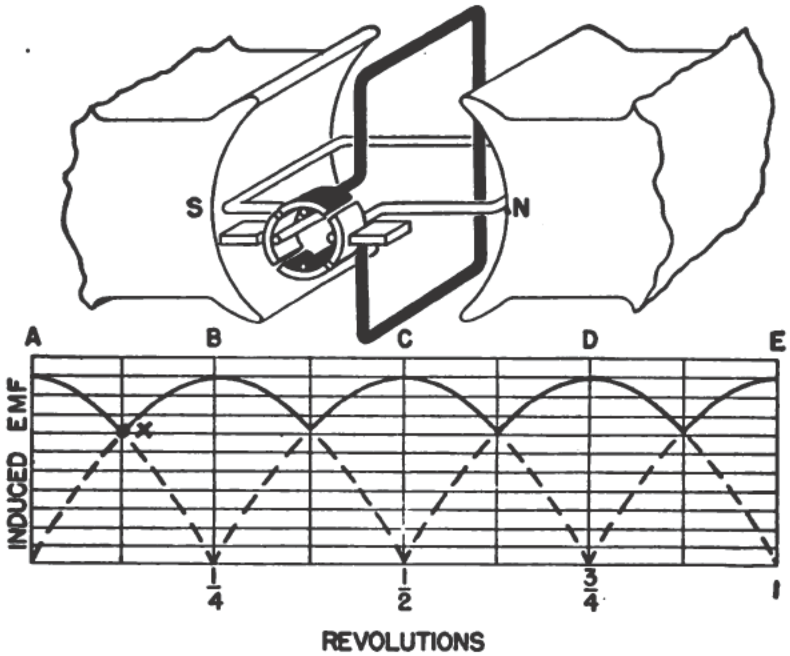


Figure 77.—Voltage from a two-coil armature.

than point X, so the bump in the voltage, called RIPPLE, is limited to the rise and fall between points A and B.

By adding more and more loops, the NUMBER of bumps increases, but the distance between the HIGHEST and LOWEST point in the emf is less—or the direct current is more nearly smooth. A heavy ripple in the voltage output of a d-c generator causes jerky operation of electrical machines and flickering of lights, so the armatures of generators have many turns to cut down ripple.

STRENGTH OF THE INDUCED EMF

The voltage induced in a single loop of wire rotating in a magnetic field is small. If the loop cuts 100,000,000 lines of force per second, an emf of one volt is induced. Two loops connected in series and cutting 100,000,000 lines of force a second would have 2 volts induced, three loops—three volts, and so on.

Now it is not necessary to have 110 loops for 110 volts, 220 loops for 220 volts, and so on, because the strength of the induced emf can be increased by turning the loop more rapidly, by increasing the flux density, or both. All of these factors are put together in a formula from which you can calculate the magnitude of the induced emf. The formula is:

$$E=\frac{\Phi SPZ}{60P'10^8}$$

where—

Φ is total number of flux lines leaving the north pole.

S is speed of armature rotation in revolutions per minute.

P is the number of poles.

Z is the number of conductors on the surface of the armature.

P' is the number of parallel paths through the armature.

The factor 60 is necessary to convert the speed in revolutions per minute (RPM) to speed in revolutions per second (RPS), and 10^8 (100,000,000) is the flux density necessary to induce an emf of 1 volt.

Right now you will not be asked to use this formula, but remember where you can find it when you need it.

QUIZ

1. Complete the following statements:
   (a) A loop of wire rotating in a magnetic field has a maximum induced voltage when the sides of the coil are moving ------ the magnetic field.
   (b) A loop of wire rotating in a magnetic field has zero induced voltage when the sides of the coil are moving ------ the magnetic field.

2. Complete the following statements:

(a) The voltage induced in a loop rotating in a magnetic field is in one direction during one half of a revolution, and in the ------ direction in the other half of a revolution.

(b) As a coil rotates in a magnetic field the voltage generated in the coil varies as a ------ wave.

(c) Each complete fluctuation of the voltage as the coil rotates through one complete revolution is called a ------.

(d) The number of complete revolutions the rotating coil makes in the magnetic field is the same as the number of ------ in the induced voltage wave.

(e) The number of complete cycles in the induced voltage wave each second is called the ------.

3. Complete the following statements:

(a) The part of a generator which rotates is called the ------.

(b) The part of a generator which does not rotate is called the ------.

(c) In an alternating current generator the currents produced in a rotating armature are led out to the external circuit by brushes pressing against ------.

(d) In a d-c generator the currents generated in the armature coils is led out to the external circuit by brushes pressing against the ------.

(e) The commutator of a d-c generator acts as a switch which ------ the connections of the coils in the armature to the external circuit.

(f) The action of the commutator makes the alternating voltage induced in the armature coils produce a ------ current in the circuit connected to the generator.

4. Complete the following statements:
   (a) The process of converting the alternating current generated in each coil of a d-c generator armature into a direct current in the external circuit, is called ------.
   (b) The voltage induced in each armature coil rises and falls ------ during each revolution of the armature.
   (c) The repeated (periodic) rise and fall of voltage in each coil as the armature rotates causes ------ in the generator output.
   (d) To cut down the rising and falling of the output voltage as the armature rotates, the number of armature conductors is ------.
5. Complete the following statements:
   To increase the voltage produced by a generator you have to
   (a) ------ the flux lines of each pole.
   (b) ------ speed of rotation of the armature.
   (c) ------ the number of conductors on the armature.
   (d) ------ the number of parallel paths through the armature.

CHAPTER 6

DIRECT-CURRENT GENERATORS

INTRODUCTION

In the last chapter you learned something about the theory and the way in which an emf is induced in a loop rotating in a magnetic field. This chapter is a description of d-c generators as you will see them aboard your ship. Any GENERATOR is a machine which CONVERTS MECHANICAL ENERGY INTO ELECTRICAL ENERGY. This is accomplished by rotating an armature, which carries conductors, in a magnetic field, thus inducing an emf in the conductors. A RELATIVE MOTION BETWEEN the conductors and the magnetic field must always exist.

In most d-c generators the armature is the rotating member and the field the stationary member, while IN most types of ALTERNATING CURRENT GENERATORS, exactly the reverse is

true—the FIELD ROTATES and the ARMATURE is STATIONARY. So to avoid confusion the rotating members of both a-c and d-c generators are known as the ROTORS, and the members that stand still as the STATORS. In either case, a mechanical force is applied to the shaft of the rotating member to cause the relative motion. Thus when mechanical energy is put into the machine in the form of a mechanical force or twist on the shaft, electrical energy in the form of a current is delivered to the external circuit.

It must be remembered also that mechanical power must be applied to the shaft constantly so long as the generator is sending electrical energy to the external electrical circuit. Don't get the idea that once the generator is started, no more power need be applied to the shaft.

The power source used to turn the shaft of the rotor is commonly called a PRIME MOVER. Many forms of prime movers are in use, such as steam turbines, Diesel engines, gasoline engines, and steam engines. However, the only prime movers used to any extent in the Navy are the steam turbine and Diesel engine.

PARTS OF A D-C GENERATOR

Figure 78 shows the principal parts of a d-c generator. The YOKE, OR FRAME, has two functions—it completes the magnetic circuit and acts as a mechanical support for the rest of the machine. In small generators the yoke usually is of one piece, but in larger types the yoke is usually made in two parts bolted together. The yoke has high magnetic properties, and with the field poles it forms the major part of the magnetic circuit. See figure 55.

The FIELD POLES are bolted to the inside of the yoke and form a core on which to MOUNT the FIELD coil WINDINGS. The poles usually are laminated to reduce eddy current losses, and serve the same purpose as the iron core of an electromagnet—to concentrate the lines of forces produced by the field coils. The entire yoke, both frame and field poles, is made from high quality magnetic iron or sheet steel.

The FIELD COILS have many turns of insulated wire and are usually wound on a form which fits over the iron core

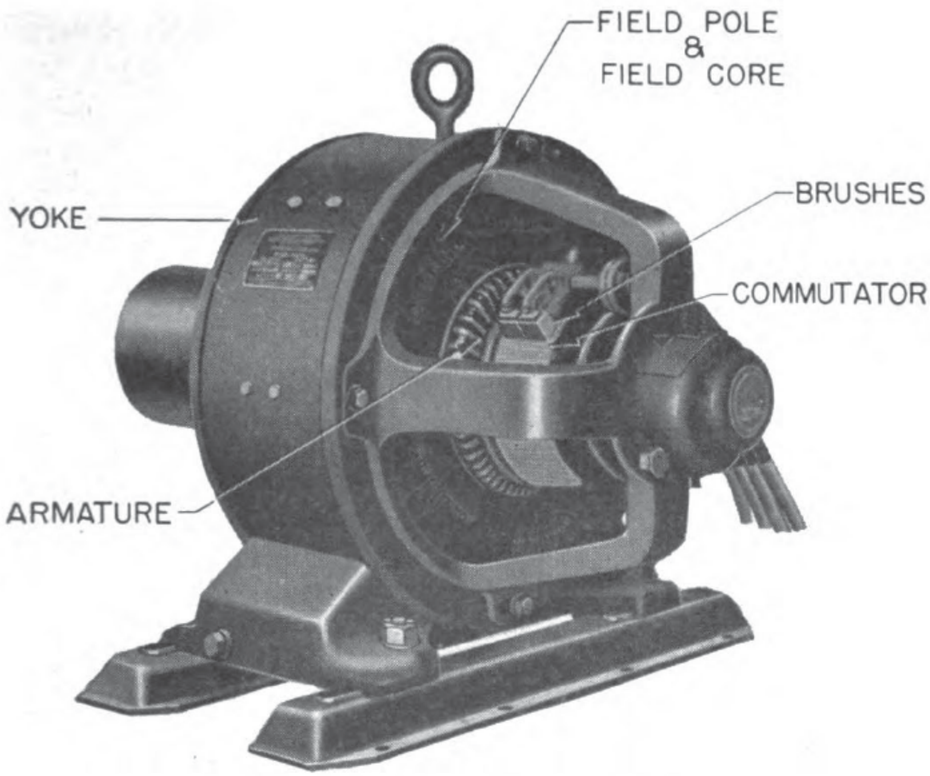


Figure 78.—Direct-current generator.

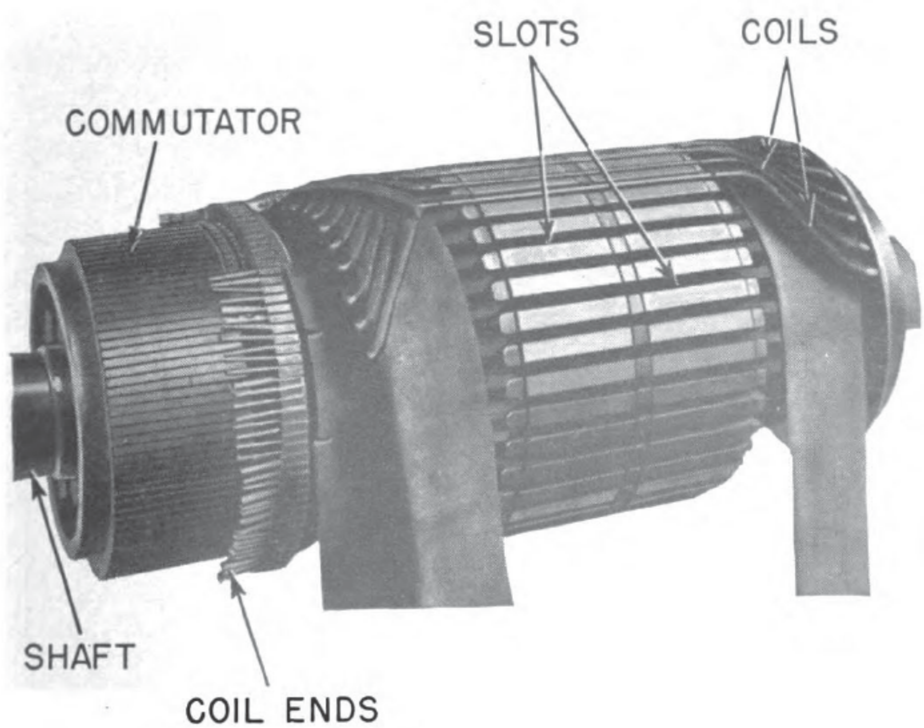


Figure 79.—Process of winding an armature.

of the pole and is securely fastened to it. The EXCITING CURRENT that causes the magnetic field flows through these coils. No electrical contact between the windings and the poles is present. Most field coils are installed so that the poles have alternate polarity. In other words, if you start at a north pole and go in either a clockwise or counter-clockwise direction around the yoke, the next pole will be a south pole, then a north pole, and so on. This is true in all generators, regardless of the number of poles, the NUMBER OF POLES always being an EVEN number.

In d-c generators, the ARMATURE revolves inside the ring of poles. The armature is mounted on a shaft, suspended at each end by bearings set in the end-bells (part of the yoke). The SPIDER is secured to this shaft and the spider in turn forms the base for the core of the armature. The core is built up from thin sheets of soft iron. The surface of the armature is slotted, and the armature coils are set in these slots. The coils are held in place and prevented from being thrown out of their slots by wooden or fiber wedges. Banding wires sometimes are wrapped around the completed armature along with the wedges to hold the coils in place. Figure 79 shows the process of winding an armature. The slots first are lined with FISH PAPER, a thin, tough paper, to help to insulate the coils from the armature core. The coils are then inserted in the slots and locked in with the wedges. Then the ends of the coils are soldered to the correct commutator segments.

Figure 80 is a sectional view of a COMMUTATOR. It is secured to the shaft, at one end of the armature. The commutator consists of wedge-shaped segments of hard-drawn copper, insulated from each other by thin sheets of mica. The segments are held in place by steel V-rings or clamping flanges fitted with bolts. Rings of mica insulate the segments from the flanges. The raised portion of each segment is called the RISER. LEADS from the armature coils are soldered to the risers, or to short slits in the ends of segments having no risers.

The brushes "ride" on the surface of the commutator and form the electrical contact between the armature coils and

the external circuit. The brushes usually are made of high-grade carbon, and are held in place by BRUSH HOLDERS, insulated from the frame. The brushes are each free to slide up and down in its holder, so they may follow irregularities

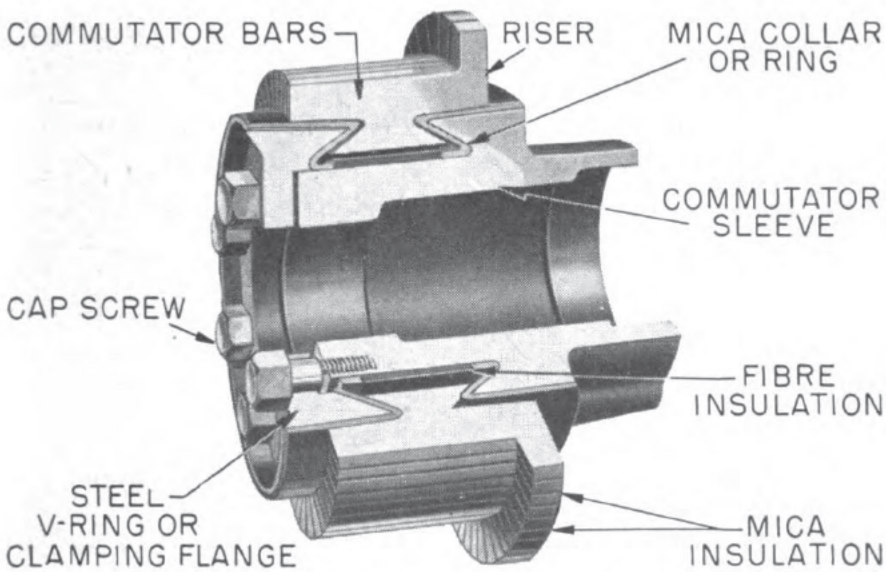


Figure 80.—Typical commutator construction.

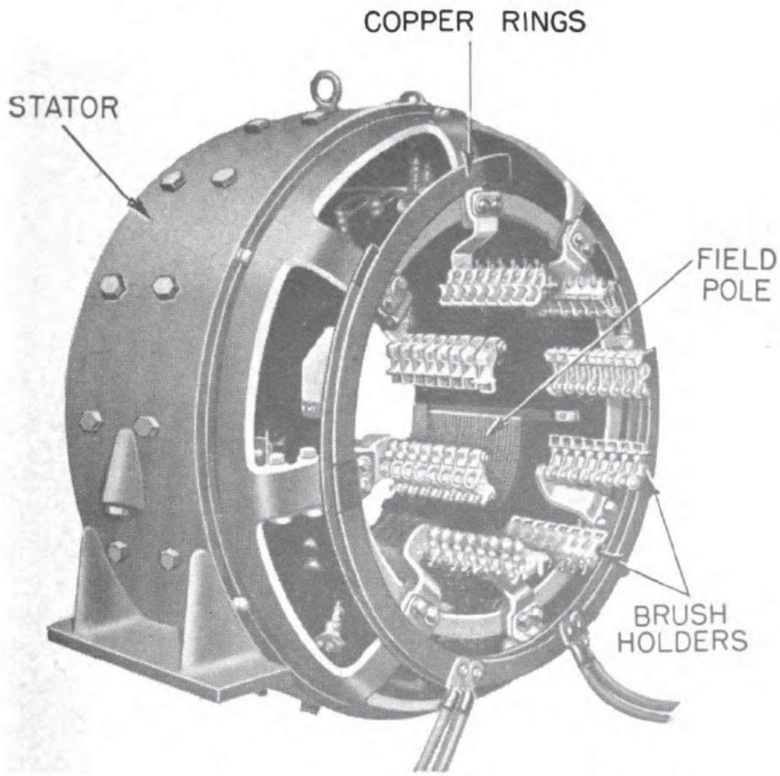


Figure 81.—Field structure and brush rigging.

in the surface of the commutator. A flexible, braided copper conductor commonly called a pig-tail, connects each brush to the external circuit. A spring causes each brush to bear on the commutator with from 1½ to 2 pounds of pressure for every square inch of brush surface riding on the commutator. These springs are usually mounted so that the brush pressure is adjustable. The brush holders are mounted on a YOKE OR ROCKER RING which permits shifting the position of the brushes about the shaft. Figure 81 shows the field structure and brush rigging of an 8-pole, low speed d-c generator. Notice the copper rings which conduct the current from the brushes to the external circuit cables at the bottom of the figure.

ARMATURES

Armatures used in d-c generators are divided into two general types, RING and DRUM. Their appearance shows the reason for their naming. Figure 82 shows the ring type.

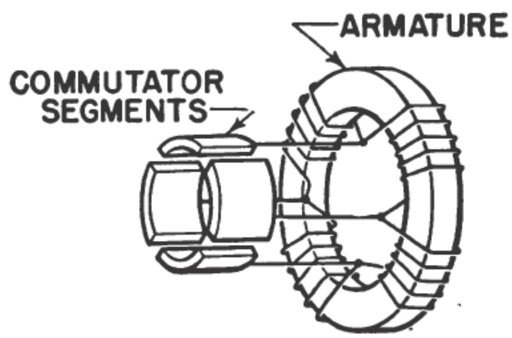


Figure 82.—Ring type armature.

It consists of insulated wire wound spirally around a hollow, iron cylinder. Taps are taken from the winding at regular intervals to form connections to the commutator segments. The ring type armature was used during development of early electrical equipment, but at present they are seldom used.

In the DRUM TYPE armature all conductors lie in slots on the armature's surface, and the individual coils are connected to each other by front and back connections, called COIL ENDS. See figures 79 and 83.

ARMATURE WINDINGS

As a rule, most d-c armatures are built with form-made coils. These coils are wound by machines giving them the correct number of turns and the proper shape. Figure 83

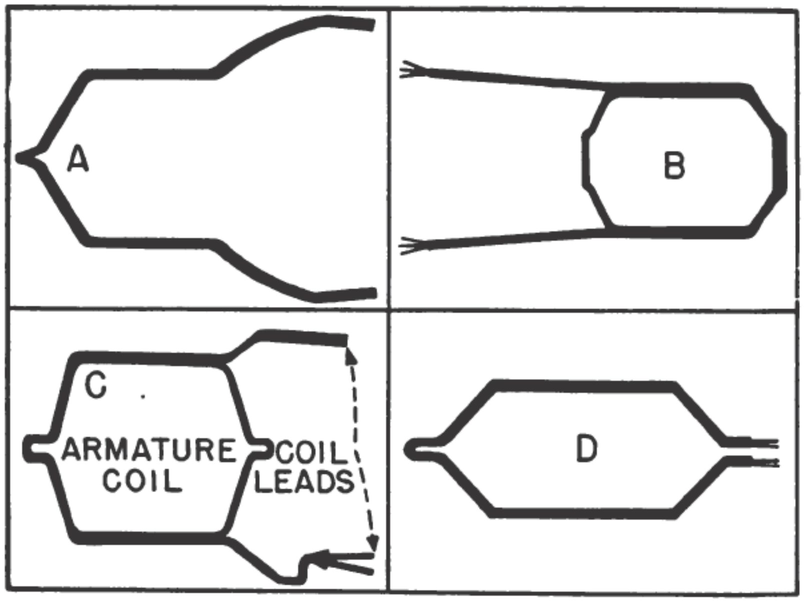


Figure 83.—Formed coils for drum armature.

shows some of the formed coils used with d-c generators. The individual windings are wrapped with insulating tape so that when a coil is placed in armature slots, it is inserted as a unit rather than by individual wires.

ARMATURE PITCH

In the preceding chapter you learned that when one leg of a generator coil was in front of a north pole, the other leg must be in front of a south pole. In commercial generators the same thing is true. If the generator is a simple two-pole affair, the windings will be placed on the armature as illustrated in figure 84. Notice how the two legs of each coil windings go to the OPPOSITE sides of the core, and thus come under OPPOSITE poles.

But suppose the generator has 4 field poles as indicated in figure 85. Now if the coil were placed in slots on the OPPOSITE side of the armature BOTH legs would be opposite

LIKE poles. Therefore, instead of placing the coils in slots on opposite sides they are placed in slots about ¼ the distance around the armature, thereby fulfilling the requirements of keeping opposite legs of the coil in front of UNLIKE poles.

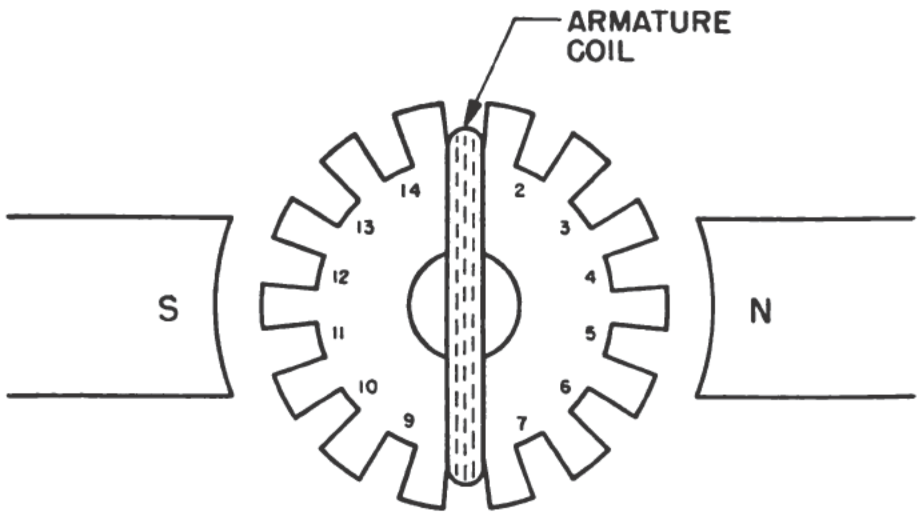


Figure 84.—Coil placement in a two-pole generator.

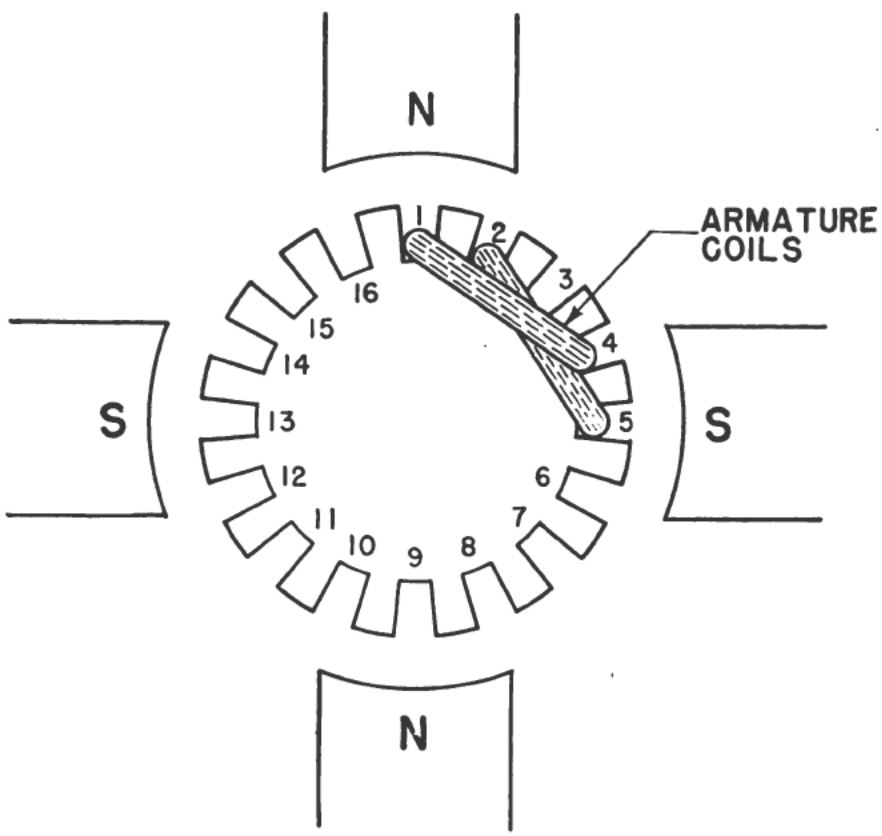


Figure 85.—Coil placement in a four pole generator.

The coils, placed on the armature, cause the armature also to have north and south poles. The DISTANCE between the centers of an armature north pole and the center of its adjacent south pole is called POLE PITCH. Thus in a 2-pole generator the pole pitch is equal to ½ the circumference of the armature, while in a 4-pole generator it is equal to ¼ the circumference. Pole pitch is expressed in the NUMBER OF SLOTS BETWEEN the centers of ARMATURE POLES and is always equal to—

$$\text{Pole pitch} = \frac{\text{Number of armature slots}}{\text{Number of field poles}}$$

Thus in figure 85, with 16 slots and 4 poles the pole pitch is—

$$\frac{16}{4} = 4$$

You will find armatures with slots that produces a pole pitch of mixed numbers, such as a 4-pole 25-slot armature. The pitch in this case is—

$$\frac{25}{4} = 6\tfrac{1}{4}$$

Since you cannot have a fractional part of a slot, the NEXT SMALLER whole NUMBER is used as the pitch. In this case it will be 6.

In winding armatures, the COIL SPAN or COIL PITCH is made as nearly equal to pole pitch as possible. For example, in figure 85, the pole pitch is 4. Therefore, the coil pitch must also be 4—meaning, the windings are placed in every fourth slot. In the 4-pole 25-slot armature, the windings would be placed in every sixth slot.

Since the coil pitch tells you how many slots to skip in the placing of the winding it is well to keep these terms in mind. Whenever you are asked to wind an armature you must use them.

LAP AND WAVE WINDINGS

Two common types of windings placed on drum armatures are LAP and WAVE. The basic difference in the two can be

observed in figure 86. The lap windings has the over-all appearance of doubling back, while the wave winding appears to be moving forward continuously.

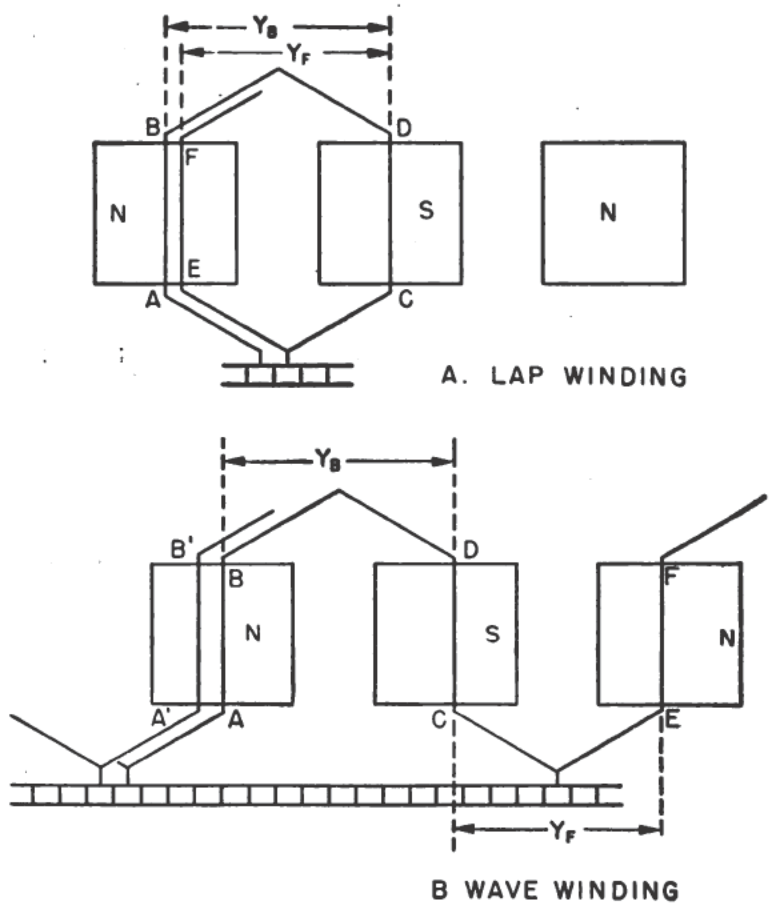


Figure 86.—Lap and wave windings.

Notice the two pitch descriptions, front and back. The BACK PITCH (Y_b) is equal to the number of elements which the end connections span, and the FRONT PITCH (Y_f) is the number of elements spanned on the commutator end.

Figure 87 shows complete winding diagrams for a lap and wave wound armature. Trace the heavy lines and observe the contacts made with the brushes. Notice also that the armature requires as many commutator segments as there are coils, whether it is lap or wave wound.

In the Training Course for Electrician's Mate 2c you will find a complete discussion on armature windings.

If you are ambitious and at this time would like to know more get a copy and study it.

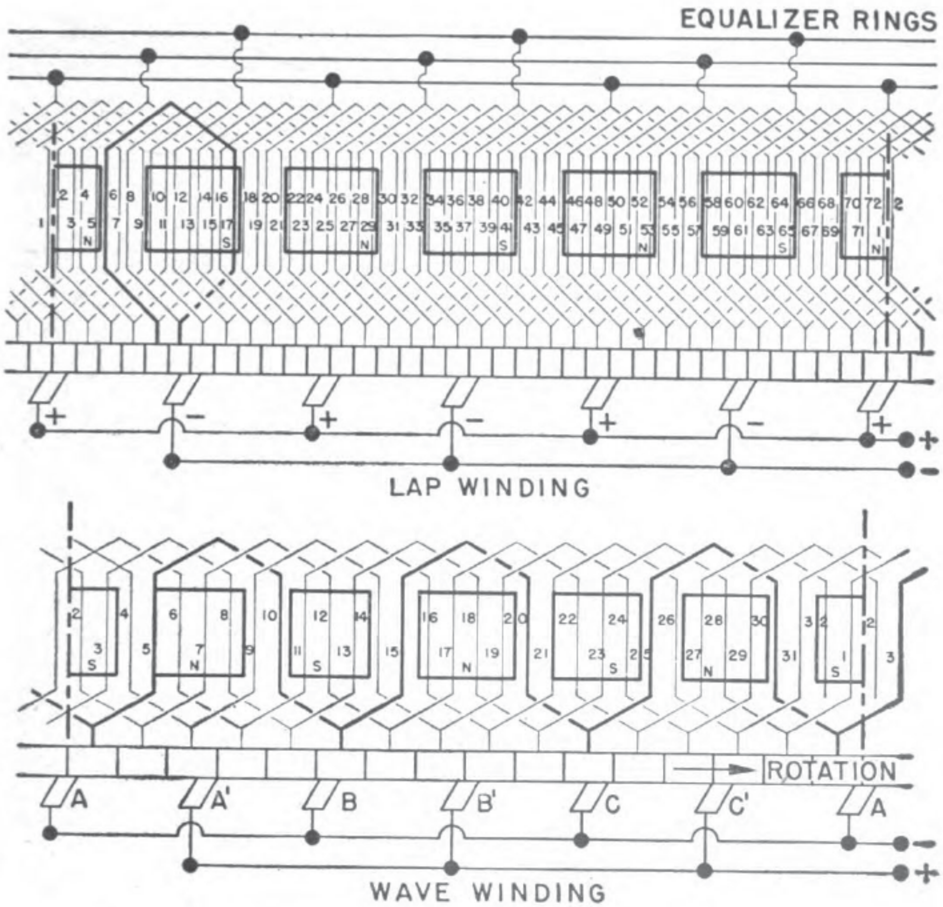
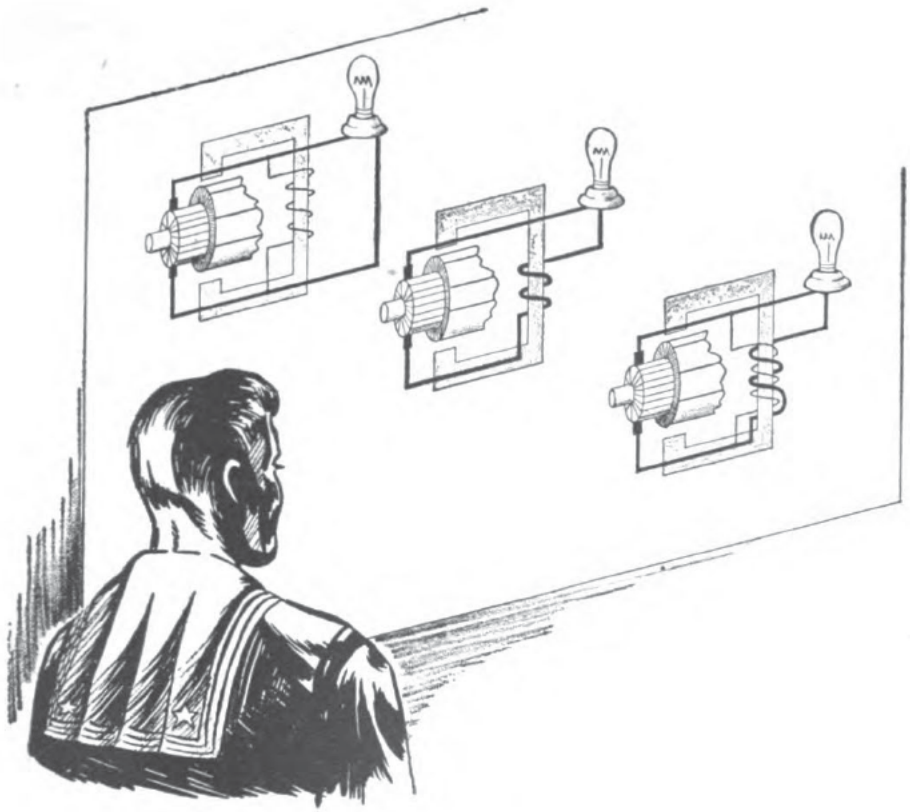


Figure 87.—Complete winding diagram, lap and wave.

QUIZ

1. What is the power source which drives the shaft of a generator called?
2. What is the structural purpose of the generator frame or yoke?
3. How is field flux produced in a d-c generator?
4. In what order must the field poles be arranged around the generator stator?
5. How are drum armature coils positioned and secured to the armature shaft?
6. What three principal parts does a commutator consist of and how are these assembled on the armature shaft?
7. What is the electrical function of the generator brushes?
8. Name the three major parts of a brush rigging and indicate the function of each.
9. Complete the following statements:
   (a) For the greatest voltage to be induced in an armature coil the two sides of the coil must be spaced to come under ------ field poles.
   (b) The distance along the armature surface, between two sides of an armature coil is called the armature ------.
   (c) The distance between the centers of an armature North pole and South pole is called the pole ------.
   (d) Pole pitch is given by the formula: Pole pitch ------.
10. A d-c generator has four field poles and 28 slots in the armature.
    What is the pole pitch?
11. Complete the following statements:
    (a) An armature winding in which the sides of the coils appear to double back is called a ------ winding.
    (b) An armature winding in which the sides of the coils appear to move continuously forward is called a ------ winding.
    (c) The number of elements spanned by a end connection at the commutator end of the armature is called the ------.
    (d) The number of elements spanned by an end connection at the other end of the armature is called the ------.
12. What is the difference in commutators for a lap and a wave type winding?



CHAPTER 7

TYPES OF DIRECT-CURRENT GENERATORS

INTRODUCTION

Direct current generators are classified according to the method used to supply the exciting current to the field windings. When the field current is obtained from a separate source, the generator is said to be SEPARATELY EXCITED. Usually this separate source is a small auxiliary generator called an EXCITER. If the field current is supplied by the generator itself, the generator is SELF-EXCITED. The self-excited class is further divided into SHUNT, SERIES, and COMPOUND types, all of which you will learn about a little further in this chapter.

GENERATOR CHARACTERISTIC

The behavior of each type of generator can be easily understood from a graph which shows the value of the generator's output voltage (voltage across its output ter-

minals) for each value of load current. Such a graph is shown for the different types of generators in figures 89, 93, and 94. This graph is called a GENERATOR CHARACTERISTIC.

To obtain this characteristic curve or graph for any generator, a test is made on the generator in which test the load on the generator is built up from nothing to full load. At each increase of load you measure the load current with an ammeter and the terminal (output) voltage with a voltmeter (fig. 88). You then plot these readings and run a line

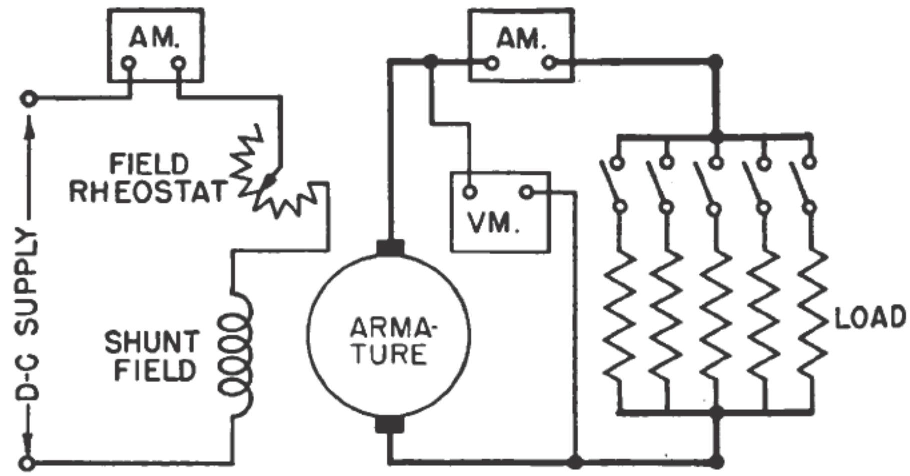


Figure 88.—Separately excited generator.

through all the separate points, which gives you a voltage-current curve such as shown in figure 89 or 93.

SEPARATELY EXCITED GENERATORS

Figure 88 shows the connections for a separately excited generator. Notice that no connection whatever exists between the field windings and the armature. The d-c supply usually is provided by another small, self-excited d-c generator.

Suppose you start up a separately excited generator with no load. After it has come up to rated terminal voltage, if you start to add load, you will find that the terminal voltage drops somewhat. This drop will increase with each increase of load. If you run this test until you reach full load, and plot the results of the test, you will obtain a curve similar to the heavy line *abf*, shown in figure 89, which is the characteristic curve for a separately excited generator.

In a separately excited generator, the terminal voltage decreases with the increase of load for two reasons. First, the armature reaction, explained later in this chapter, weakens the flux produced by the main field windings and therefore reduces the emf induced in the armature conductors. Second, there is a voltage drop in the armature itself due to current flowing through the resistance of the windings. This drop also increases with increases of load. Thus the net voltage at rated load is represented in figure 89 by line

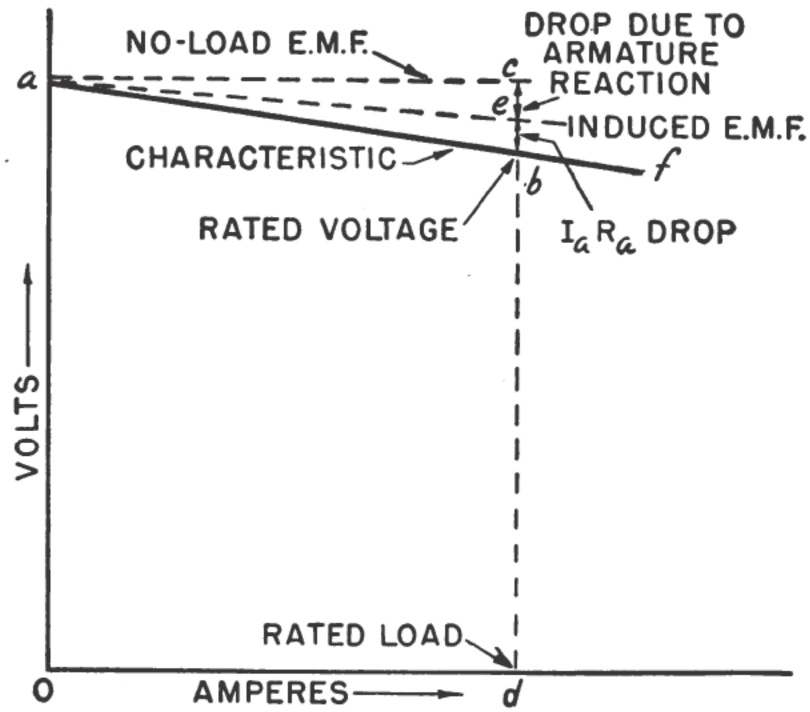


Figure 89.—Characteristic of separately excited d-c generator.

bd. The line *af* represents the general characteristic of the separately excited generator.

The Navy uses very few separately excited d-c generators to provide power for regular ship's power and lighting circuits. But this type of generator is widely used by the Navy in AMPLIDYNE and similar automatic control systems for positioning searchlights, guns, directors, etc. In these systems, the separately excited generator feeds only the driving motor which positions the guns or searchlight. By using separate (external) excitation, it is easy to change the generator's output to the driving motor, and thus to change

the speed and direction of movement of the guns. You will learn more about these systems in the chapter on searchlights.

SELF-EXCITED D-C GENERATORS

Self-excited d-c generators are divided into three general types—SHUNT, SERIES, and COMPOUND. In the SHUNT type, the FIELD circuit is connected across the generator terminals, IN PARALLEL WITH the LOAD, as shown in figure 90B. A field rheostat usually is connected in series with the shunt field. The shunt field is composed of a large number of turns of comparatively high resistance wire, so only a small portion of the total generator current will flow through the field.

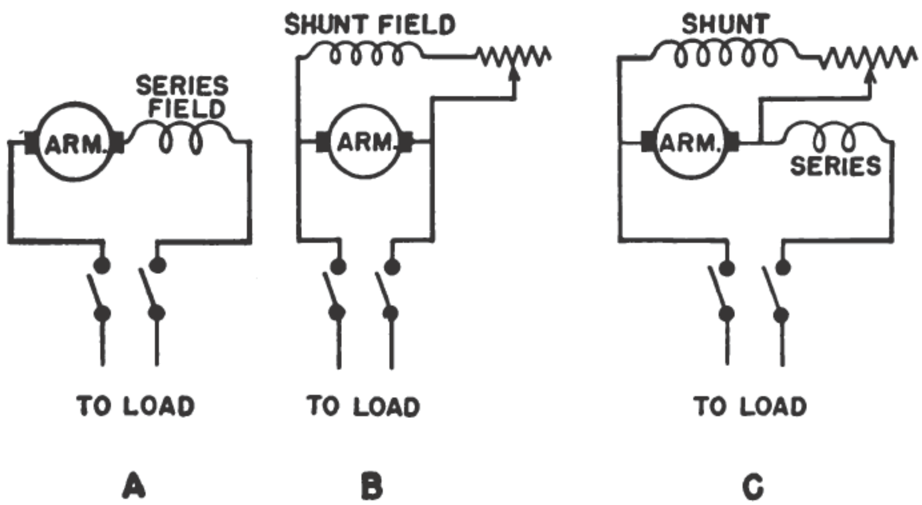


Figure 90.—Self-excited generators.

The SERIES type generator is excited by a FIELD winding of comparatively few turns of low-resistance wire connected IN SERIES WITH the armature and LOAD. This type generator connection is illustrated in figure 90A.

The COMPOUND generator has a combination of both shunt and series fields. The series winding usually is connected so that its flux aids that of the shunt field. Hence, you get an increase of main field flux with increase of load. The compound generator connections are shown in figure 90C.

GENERATOR BUILD-UP

Consider what happens when you are starting up a self-excited generator such as the shunt type shown by the

diagram of figure 90B, In such a generator the output voltage will change as you change the field current as shown by the curve of figure 91.

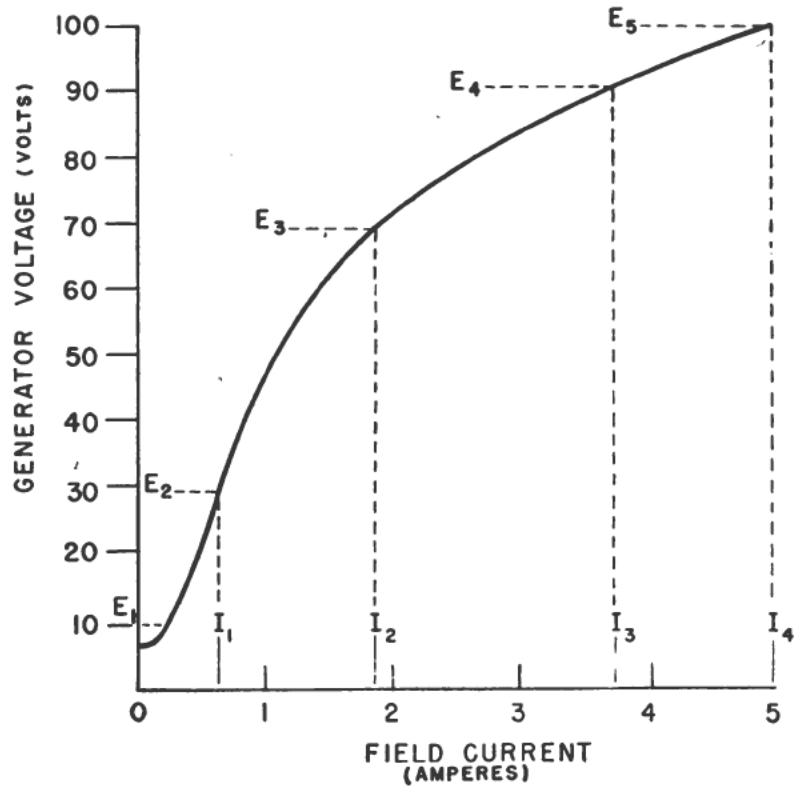


Figure 91.—Generator build-up.

When the generator starts rotating there is no current in the field windings. But there always is a slight amount of residual magnetism in the field poles. This residual magnetism provides a small flux which is cut by the armature conductors, producing a small generator output voltage, E_1. This voltage acts across the shunt field, producing a current in the field windings. If the field resistance is R, the field current, I_1, by Ohm's law, will be—

$$I_1 = E_1/R.$$

But with a current I_1 flowing in the field coils, the flux is increased, producing an increased voltage E_2; and with E_2 across the field winding, the field current increases to I_2. This larger field current in turn produces a still larger flux,

which increases the generator voltage to E_3; E_3 in turn produces a larger current I_3, which again increases the flux, which again increases the voltage to E_4, and so this process goes on, each increase in voltage automatically producing another voltage increase until the generator voltage is built up to its full value, E_5.

In short, when a self-excited generator is started up, the residual field magnetism produces a small initial voltage. This voltage, producing current in the field windings, starts an automatic process of increasing generator output voltage, and this increase goes on until the full normal generator voltage is built up. This explanation will help you understand why self-excited generators sometimes do not come up to their rated voltage and what to do about it.

STARTING SELF-EXCITED GENERATORS

Occasionally a self-excited generator, particularly a shunt generator, may fail to build up its terminal voltage. When this happens one of the following reasons may explain why.

INSUFFICIENT RESIDUAL MAGNETISM. To correct this, "flash" the generator field by connecting a low voltage line or a battery across the shunt field, allowing the current to flow and magnetize the field cores.

THE SHUNT FIELD RESISTANCE IS TOO HIGH. Reduce the resistance of the shunt-field circuit by manipulating the field rheostat.

THE SHUNT FIELD CONNECTIONS ARE REVERSED. Reverse the connections.

THE SHUNT FIELD CIRCUIT IS OPEN. Find the break and repair it.

SHUNT GENERATORS

In figure 92, the curve *ab* shows a typical shunt-generator characteristic. It shows that the terminal voltage drops as the load is increased. Three factors contribute to the drop in terminal voltage as the load is applied: ARMATURE RESISTANCE, ARMATURE REACTION, and DECREASE IN FIELD CURRENT. In a shunt generator the armature provides both the load and field currents. Therefore as load increases arma-

ture current increases. The terminal voltage drops at first because the armature reaction and armature resistance drops both increase as the armature current increases. The lowered terminal voltage results in a decrease in field current. The decreased field current means less lines cut per second by the armature conductors, and this still further lowers terminal voltage.

Over the normal operating region, *ab*, the drop in generator voltage as the load is increased is relatively small. The shunt generator is therefore considered to be a CONSTANT-POTENTIAL generator, and so it is used where a practically constant voltage is desired regardless of change of load. When operating in parallel, shunt generators are practically completely self-adjusting in holding line voltage constant under fluctuating load conditions.

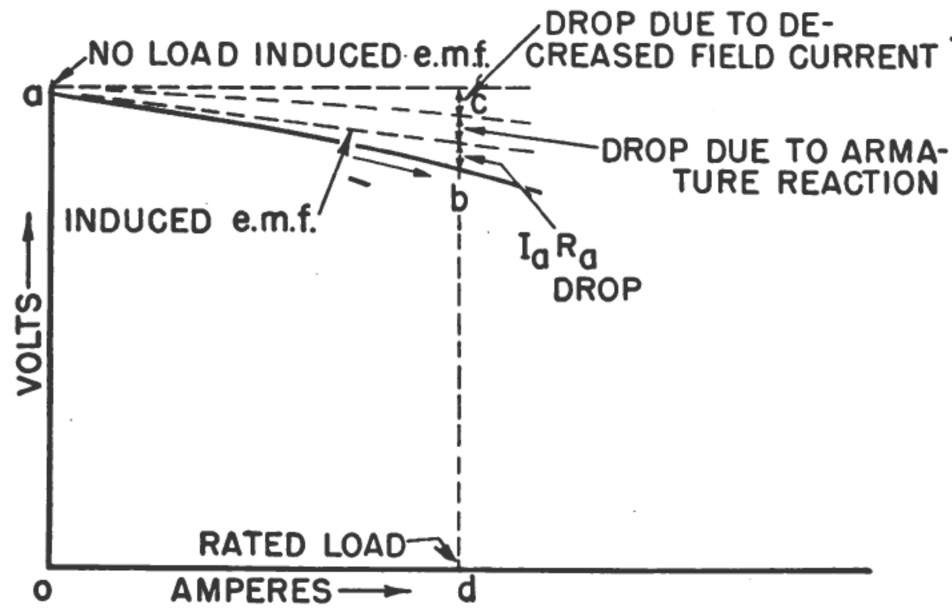


Figure 92.—Characteristic of a shunt generator.

As you have seen in the preceding paragraph, when the shunt generator is started, there is no voltage across its terminals, hence no field current, but there is a small amount of RESIDUAL MAGNETISM present in the iron core which produces a small emf which produces a small current through the field windings, increasing the flux of the field, and this increased flux causes a further increase of induced emf. This process continues automatically until full generator voltage is built up.

It might seem that the terminal voltage of a shunt generator would continue to build up indefinitely. However, it does not, because saturation of the magnetic circuit will not permit it. In figure 91, the flat top part of the curve is where saturation occurs—that is, a large increase in the field current will cause only a small increase in flux. Hence in this region a large increase in field current produces only a small increase in terminal voltage, and the voltage self-build up process stops.

The voltage in the external circuit of a shunt generator can be regulated by varying the resistance in series with the field coils. This feature provides a convenient means for controlling the output voltage of a shunt generator.

VOLTAGE CONTROL AND VOLTAGE REGULATION

In d-c generators, two terms, voltage control and voltage regulation, are quite alike, but enough different to cause considerable confusion.

VOLTAGE CONTROL refers to ANY CHANGE IN the TERMINAL VOLTAGE of a generator BROUGHT ABOUT INTENTIONALLY by manual or by automatic operation of some auxiliary regulating apparatus, such as a field rheostat.

VOLTAGE REGULATION refers to those CHANGES IN the TERMINAL VOLTAGE of a generator that are shown by the generator characteristic, and WHICH OCCUR AUTOMATICALLY, due to the reactions that go on within the generator when the load changes. As an example, it is inherent in the design of a shunt generator for the terminal voltage to drop when a load is applied.

Voltage regulation usually is expressed as a percentage. The PERCENTAGE REGULATION is the RATIO of the CHANGE IN VOLTAGE between no load and full load TO what the VOLTAGE is AT FULL LOAD. The formula for finding this percentage is—

$$\%\ \text{regulation} = \frac{(\text{no-load } E) \text{ minus } (\text{full-load } E) \times 100}{\text{full-load } E}$$

For an example, the voltage of a shunt generator when operating at no load is 112, and when operating at full load is 108. Find its voltage regulation.

Substituting in the above formula, we have:

$$\% \text{ regulation} = \frac{112-108}{108} \times 100 = \frac{400}{108} = 3.7\%$$

Remember the SMALLER its numerical value, the BETTER THE voltage REGULATION. It is important to keep voltage regulation small because even a small drop in their supply voltage greatly cuts down the brightness of the lamps and the speed of motors connected to the generator.

COMPOUND GENERATORS

By placing a few turns of wire on the field poles in series with the armature and the load, a shunt generator may be made to produce a substantially constant voltage, or even a rise in voltage, as the load increases. These turns are usually wound and connected so they aid the shunt turns. As the load increases, the current through the series winding also increases and therefore increases the field flux. This increased flux causes an increase in the induced emf. By properly adjusting the amount of current which flows in the series winding, the increase in induced emf can be made to balance the drop in voltage due to armature reaction and

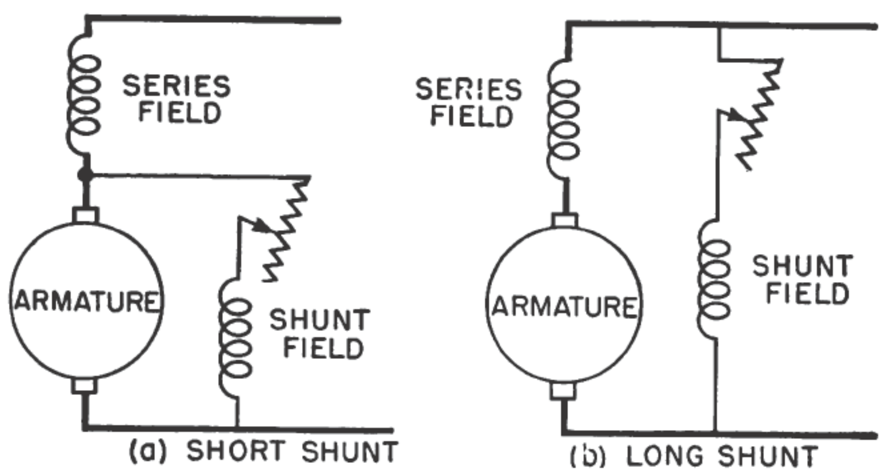


Figure 93.—Types of compound generators.

armature resistance. In this way the series winding more or less neutralizes the causes of voltage drop present in a shunt generator.

In a compound generator the shunt field may be connected

across the armature terminals directly to form a SHORT-SHUNT compound generator, or the shunt field may be connected in parallel with both the armature and the series field to form a LONG-SHUNT compound generator. Both connections are illustrated in figure 93. The characteristics are practically the same in either case.

When the series field is connected so it AIDS the flux of the shunt field, the generator is said to be CUMULATIVE-WOUND. When the series field flux OPPOSES the flux produced by the shunt field, the generator is DIFFERENTIAL-WOUND. The latter type seldom is used because of its very poor voltage characteristic—in some cases the terminal voltage drops to zero before rated load can be applied on the generator.

CHARACTERISTICS OF COMPOUND GENERATORS

If a compound generator produces the SAME terminal voltage at rated load as at no load, the generator is FLAT-COMPOUNDED (Fig. 94). Flat-compounded generators are

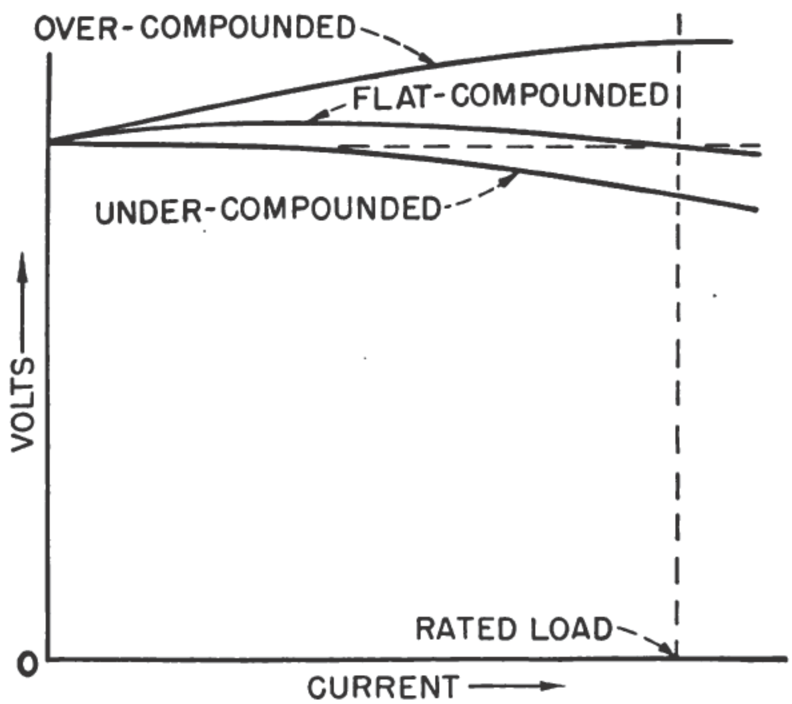


Figure 94.—Compound generator characteristics.

used principally where the circuit feeder lines are short and it is desirable to have the voltage maintained at a constant level for all loads without adjusting the shunt field rheostat.

When the rated load voltage is GREATER than the no-load voltage, the generator is OVER-COMPOUNDED (Fig. 94). Over-compounded generators are used where the load is located some distance away from the generator. As the load increases, the voltage at the load tends to decrease, due to the voltage drop in the feeder. However, if the generator voltage rises just enough to offset this feeder drop, the voltage at the load remains constant.

When the rated-load voltage is LESS than the no-load voltage, the generator is UNDER-COMPOUNDED. These generators seldom are used. The characteristic curve of the three types of compounding are illustrated in figure 94.

The characteristics of all three types of compound generators tend to droop because, due to saturation, the series field winding does not increase the flux at full load in the same proportion as it does at light load.

Compound generators are usually wound to be somewhat over-compounded. The degree of compounding can then

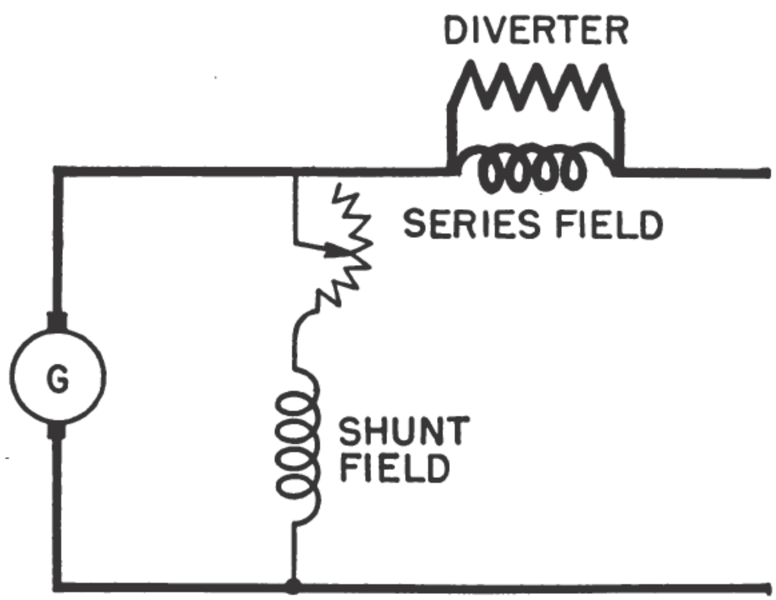


Figure 95.—Series field diverter.

be regulated by shunting more or less current away from the series field. This is done by placing a low-resistance shunt, commonly called a DIVERTER OR COMPOUNDING RESISTOR, across the series field terminals as shown in figure 95.

The terminal voltage of a compound generator is built up in the same manner as that in the shunt machine—by the presence of a residual magnetism in the field poles. The voltage supplied to the external circuit is controlled by the same method as that used in a shunt generator—by manipulation of the shunt field rheostat.

PERCENTAGE OF OVER-COMPOUNDING

The formula used to calculate the percentage of over-compounding in a compound generator is similar to the one given previously for calculating the percentage of voltage regulation. Do not confuse the two. The new formula is—

$$\%\ \text{Over-compounding} = \frac{(\text{full-load } E) \text{ minus } (\text{no-load } E)}{\text{no-load } E} \times 100$$

EXAMPLE: The voltage of a compound generator when operating at no load is 110 and when operating at full load is 115. Find its percentage of over-compounding. By formula—

$$\%\ \text{Over-compounding} = \frac{115-110}{110} \times 100 = \frac{5.0}{110} = 4.5\%$$

Before going on, go back and look at the formula for voltage regulation and observe the difference between the two.

SERIES GENERATORS

In a SERIES GENERATOR the field coils are in series with the armature. The windings have a low resistance, since all the current from the external circuit and armature must flow through them. The ampere-turns strength of a series generator, as compared with those of the shunt machine, are the product of a much larger current and a lesser number of turns. With the armature running at a constant speed, the emf and current from a series generator will vary with every change in the resistance of the external circuit, since each change of current alters the field magnetizing current.

Ordinarily, series generators are used for CONSTANT-CURRENT work, in distinction from the shunt generator, which maintains substantially CONSTANT VOLTAGE.

To control the terminal voltage of a series generator, a rheostat is placed in shunt (parallel) with the series field. The main current divides in proportion to the resistances of the two circuits. Obviously a series generator will not self-excite when the external circuit is open, and will not "build up" when the external resistance is very high.

Series generators formerly were used as constant-current generators to operate arc lamps connected in series but few of them are now in service. Series generators are not used aboard Naval vessels at present.

THREE-WIRE GENERATORS

Some ships have 3-wire d-c generators capable of supplying 240 volts to the power circuits and 120 volts to the lighting circuits. This arrangement is based on the fact that power equals $E \times I$, and if you increase E, you can decrease I for the SAME AMOUNT OF POWER. The decreased I saves a great deal in the I^2R copper (heat) losses explained in chapter 1. Motors of certain horsepowers are more efficient when supplied with high voltage and low current; while lights, on the other hand, are difficult and expensive to make for use with high voltages.

The 3-wire generator is similar to the 2-wire generator in operation. It developes 240 volts across the armature terminals. The generator is arranged so a third wire or NEUTRAL wire is brought out from a point MIDWAY in potential between the positive and negative terminals. This provides for a lead at HALF GENERATOR VOLTAGE. This mid-voltage is obtained by connecting a REACTANCE COIL, called a STATIONARY COMPENSATOR, across the armature winding through the collector rings. The neutral wire is connected to the mid-point of the compensator.

One type of 3-wire generator, designed by Dobrowolsky has a low-resistance compensator coil of heavy wire wound on an iron core. The coil is mounted on the armature and connected as shown in figure 96. In a bipolar generator of this type, the coil is connected to the regular armature winding at diametrically opposite points *a* and *b*. The neutral wire is joined to the midpoint *c* of the coil by a slip ring and

brush. The emf across the terminals *a* and *b* is alternating, and consequently an alternating current will flow through the coil, but its value is small because of the large inductance of the coil. The midpoint *c* has a potential midway between the potentials of the brushes connected to the outside wires. If the LOAD taken from one side of the circuit is EQUAL to the load taken from the other, NO direct CURRENT will flow IN the NEUTRAL WIRE nor through the coil. But IF the LOADS ARE UNBALANCED, the NEUTRAL WIRE and coil WILL CARRY a direct CURRENT equal to the difference in currents, or the amount of UNBALANCED CURRENT in the two circuits.

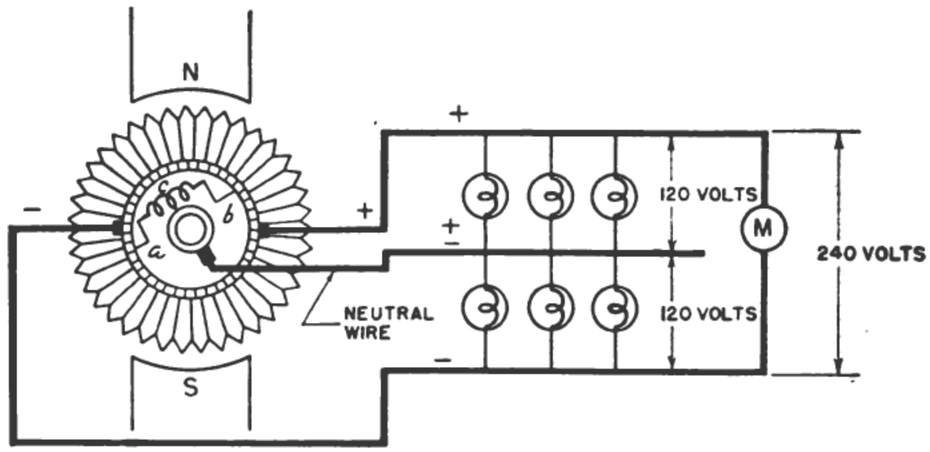


Figure 96.—Three-wire generator.

The saving in copper is the chief advantage in using the 3-wire distribution system. Only ⅜ as much copper is required as in the 2-wire system. The neutral wire never carries over 25% of the rated current output of the generator, and therefore it can be much smaller than either of the two outer wires.

A disadvantage of the 3-wire system is present if the neutral wire is opened when the load is unbalanced. One of the two circuits is then subjected to an excessive voltage, because the two circuits are in series across 240 volts. If lamps are subjected to excessive voltage they will either burn out immediately or have their life shortened considerably.

In compound three-wire generators the series field coils are divided into two equal sections, one section connected in series with one of the outer wires and the other section being connected in series with the other outer wire. In the chapter

on OPERATION OF D-C GENERATORS, you will learn that EQUALIZERS are necessary for operating compound generators in parallel. In connecting two compound three-wire generators in parallel, two equalizers are required, one for each half of the series field. So don't be surprised if you find two equalizer switches for each machine on the main switchboards of some ships.

ARMATURE REACTION

Part *A* of figure 97 shows the flux from the field poles and through the armature when there is no current in the armature conductors. This flux is due entirely to the ampere-turns of the field. Notice the NEUTRAL PLANE. It is the plane PERPENDICULAR to the flux, and coincides with the geometrical center of the system. Now in your study of elementary mathematics you learned that the DIRECTION and STRENGTH of any quantity, such as a magnetic field, can be represented by the DIRECTION and LENGTH of an arrow, called a VECTOR. Thus in the vector diagram at the right of figure 97A vector *F* represents the direction and magnitude of the field flux. The neutral plane is therefore at the right angles to this vector *F*.

Figure 97B shows the flux that would exist if no current is flowing in the field coils, but the armature conductors are carrying a current. This current is in the same direction in the armature conductors as it would be if the generator were under load, with field poles and direction of rotation as indicated.

From the left-hand rule, you see that the magnetomotive forces due to the conductors on the left-hand side of the armature would combine to send a flux DOWNWARD through the armature, as shown in the diagram. And the same is true for the conductors on the right-hand side of the armature. That is, the mmf's due to the conductors on BOTH sides of the armature combine in such a manner as to send flux DOWNWARD through the armature. The direction of this flux is PERPENDICULAR to the axis of the main field poles. To the right of the figure this armature flux is represented in magnitude and direction by the vector F_A.

When the generator is rotating and is under load, the field current and the armature current act simultaneously, producing both the fields shown in figures 97A and 97B, at once. The armature flux then crowds the field flux toward the direction of rotation, as shown in figure 97C. Thus, if the armature is rotating in a clockwise direction, as shown in

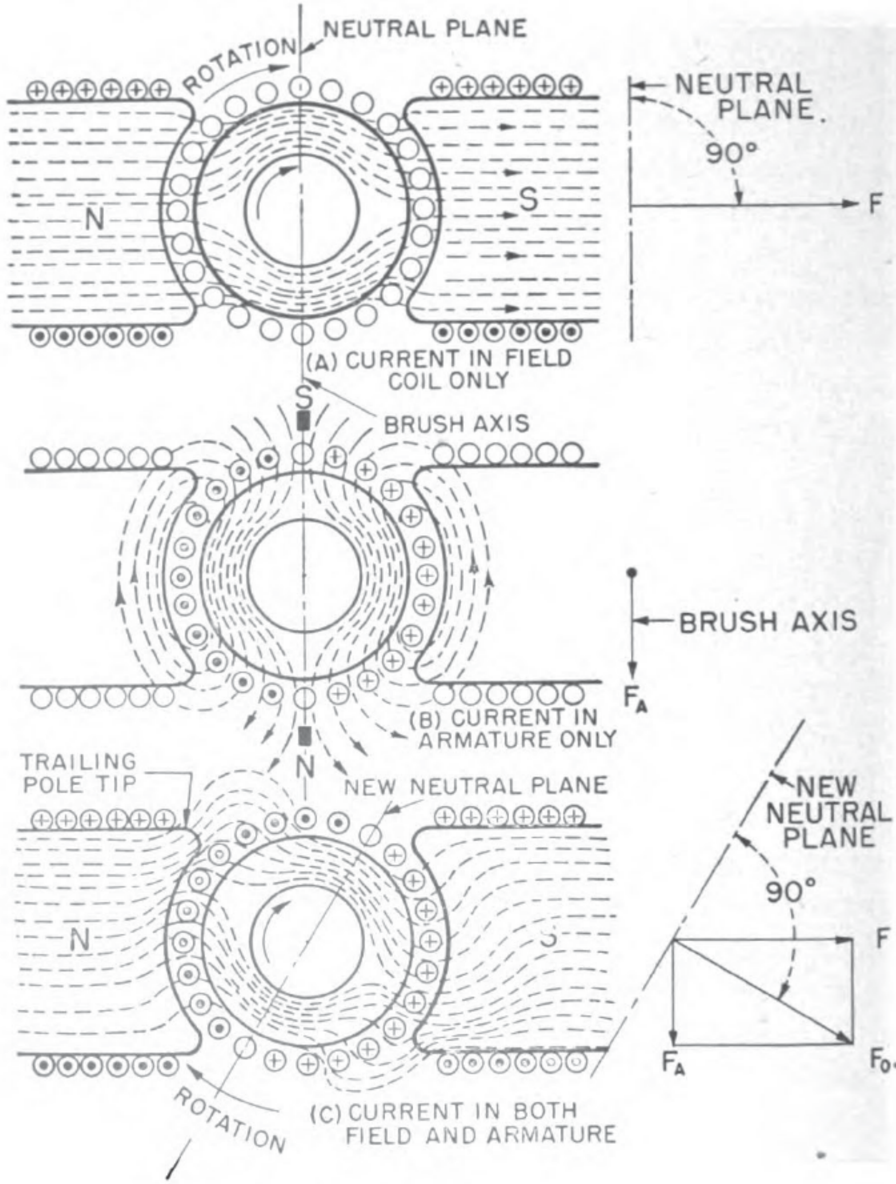


Figure 97.—Armature reaction.

figure 97C, the flux is crowded into each TRAILING pole tip, strengthening the field there, while the flux at the LEADING pole tip is weakened.

The effect of ARMATURE CURRENT is thus to DISPLACE THE FIELD IN THE DIRECTION OF ROTATION of the generator. Be sure you understand that the FLUX IS NOT PULLED AROUND BY THE MECHANICAL ROTATION OF THE ARMATURE. It is forced there by the interaction of the two magnetic fields.

The effect of the armature reaction in this case is also shown by vectors to the right of figure 97C. The field vector F and the armature vector F_A combine at right angles to form the resultant field vector F_O. The direction of F_O is downward and to the right, corresponding to the general displacement of the flux.

ARMATURE REACTION—WHAT IT DOES TO COMMUTATION

Here is the important point about armature reaction. In figure 97C, the neutral plane is drawn perpendicular to to Vector F_0. Due to armature reaction, that is the new position the armature conductors must be in to have zero induced voltage. As you learned in Chapter 5 in the paragraph on COMMUTATION, the BRUSHES in a generator are placed ALONG THIS NEUTRAL PLANE, so that there is no induced voltage in the conductors when they are short circuited by the brushes. So—if armature reaction caused the neutral plane to advance, you MUST MOVE THE BRUSHES FORWARD, in the direction of rotation, until they are advanced to the new neutral plane. If the brushes are not advanced far enough, or if advanced too far, conductors carrying heavy current will be SHORT CIRCUITED, causing ARCING between the brushes and commutator.

HOW ARMATURE REACTION REDUCES VOLTAGE

Figure 98 shows that portion of the ampere-conductors which are included within an angle β on either side of the geometrical neutral, where β is the angle of brush advance. The conductors at the top of the armature are carrying current out of the paper, since they are to the left of the brush axis. By applying the left hand rule you will find the mmf through the armature is acting from right to left. The

conductors at the bottom of the armature carry current into the paper, because they are at the right of the brush axis. Their mmf through the armature also acts from right to left. Referring to figure 97C again, the mmf of the main poles acts from left to right. Hence F_D, the mmf of the ampere-conductors included within twice the brush angle at both top and bottom of the armature, OPPOSES the mmf of the main field and therefore tends to REDUCE the flux through the armature. These conductors are called DEMAGNETIZING AMPERE-CONDUCTORS.

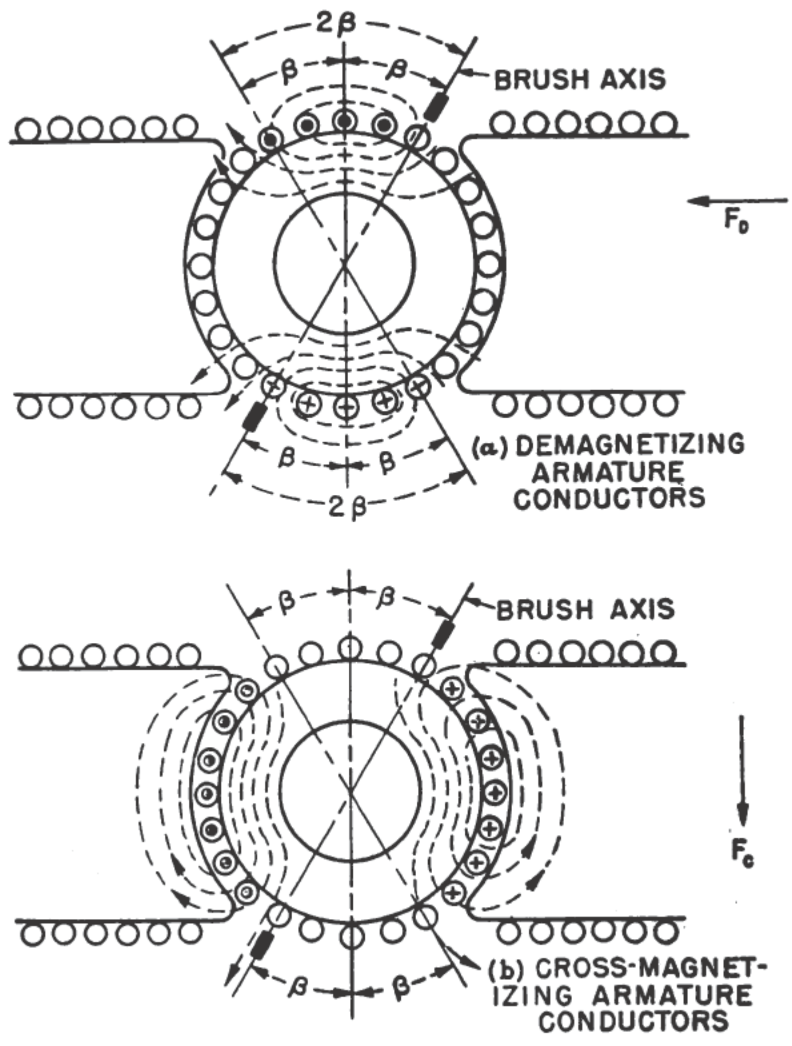


Figure 98.—Demagnetizing and cross-magnetizing components of armature field.

Figure 98B shows the armature ampere-conductors of figure 97C which are not included in figure 98A. The mmf

of the conductors on both left and right-hand sides of the armature, F_C, acts downward and hence at right angles to the mmf of the main field, as shown in figure 98B. These conductors are called CROSS-MAGNETIZING AMPERE-CONDUCTORS.

In short, if the generator is carrying load and the brushes are advanced, the armature ampere-conductors tend to both DEMAGNETIZE and to CROSS-MAGNETIZE the main magnetic field. These magnetizing mmfs in the armature constitute ARMATURE REACTION. Armature reaction has an important effect in the operation of all generators. Extra field pole windings, called interpoles or commutating poles, sometimes are used to reduce its effect. These windings, or compensating windings, will next be discussed.

CORRECTING ARMATURE REACTION—INTERPOLES

You have just learned that when a load is applied to a generator, the flux is crowded into the trailing pole tips by the MMF of the armature ampere-conductors. If the brushes are allowed to remain in the GEOMETRICAL neutral, sparking will occur, because the coils undergoing commutation are generating an emf and are short-circuited by the brushes. This effect of this reaction is indicated in figure 99. You

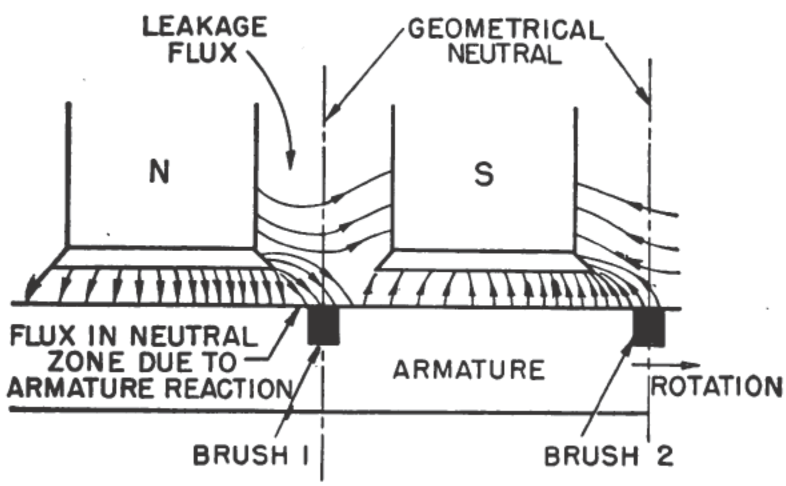


Figure 99.—Flux distortion due to armature reaction.

also learned that this difficulty may be overcome by moving the brushes to the new neutral plane produced by the arma-

ture reaction. But the amount of armature reaction—that is, the amount of shifting of the neutral plane—will depend on the amount of current in the conductors; that is, on the load. So for every change in load the brushes will have to be moved to a new position. To do that would be a nuisance, so you leave the brushes in their geometrical neutral position and use an arrangement which automatically neutralizes the effect of armature reaction at all loads. This arrangement is provided by small auxiliary poles, called INTERPOLES, built into the generator.

If a small auxiliary south pole (interpole) of the proper strength is placed in the interpolar region between both main poles, as shown in figure 100, the north pole flux

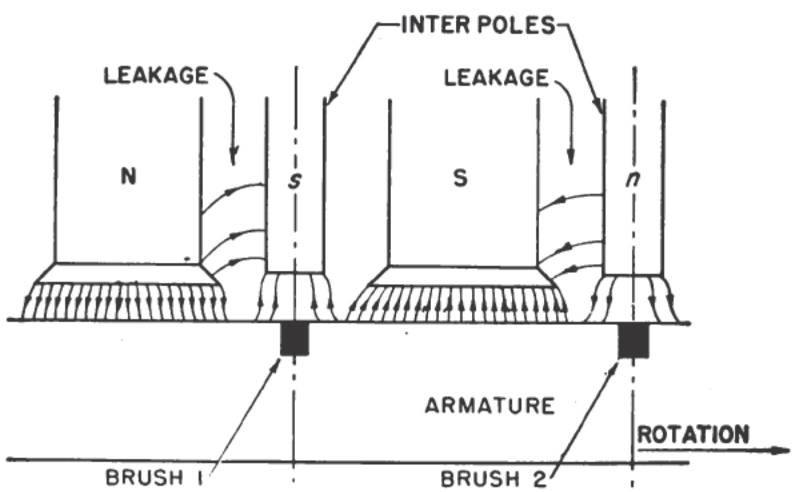


Figure 100.—Effect of interpoles on flux distortion.

which enters the armature midway between poles will be neutralized. Therefore, if this interpole (commutating pole) is adjusted correctly, good commutation at all loads is obtainable. Obviously, an interpole of north polarity should be placed in the commutating region of brush 2.

Armature reaction is practically proportional to the armature current. Thus, the interpole flux which neutralizes flux distortion must be proportional to the armature current. To accomplish this the interpoles are excited by a winding connected in SERIES with the armature, as shown in figure 101. Interpoles usually have a larger number of turns than

is necessary to produce good commutation. Formerly, the poles were adjusted to the proper strength by means of a shunt or diverter connected across the interpole circuit. Modern practice adjusts the effect of the interpoles by the use of shims between the interpole and yoke. If the inter-

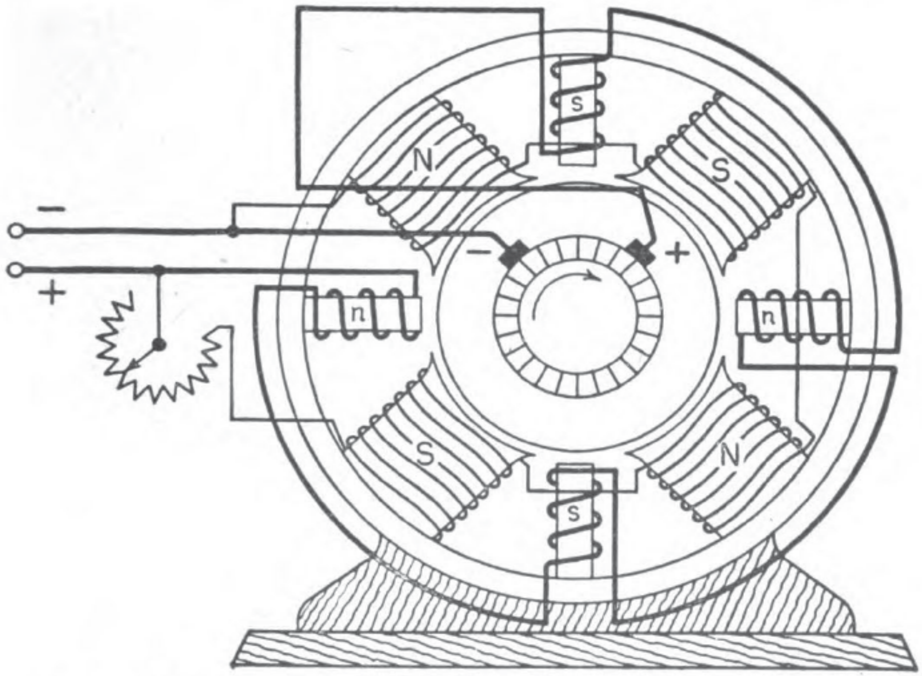


Figure 101.—Connections for shunt field and commutating poles.

poles are adjusted properly, it is not necessary to shift the brushes with change of load.

It should be noted that in a generator THE SEQUENCE OF main and commutating POLES is IN THE DIRECTION OF ROTATION or N-s-S-n, where the capitals are the main poles and the small letters the interpoles. Notice that the interpoles compensate the flux in the neutral zone only and do not compensate for the distortion of the flux over the entire surface of the pole.

CORRECTING ARMATURE REACTION—COMPENSATING WINDINGS

The current in the armature of a generator is responsible for the cross-flux that produced distortion of the magnetic field and necessitated a shift of the brush axis. This shift,

as you learned in the preceding paragraph, can be neutralized by interpoles. Another method of doing the same thing is also possible. If the mmf which sets up this cross-flux were neutralized by a current equal and in the opposite direction, there would be no cross-magnetizing flux, and it would be unnecessary to shift the brushes when the load on the machine changes. To accomplish this, compensating windings should be placed in a position that permits the armature coils undergoing commutation to have emf induced in them that will cancel the voltage present in the coils. Then the brushes may be located centrally and permanently for all loads.

Such compensating windings are formed by COILS embedded IN SLOTS IN THE FIELD POLES, through which coils the

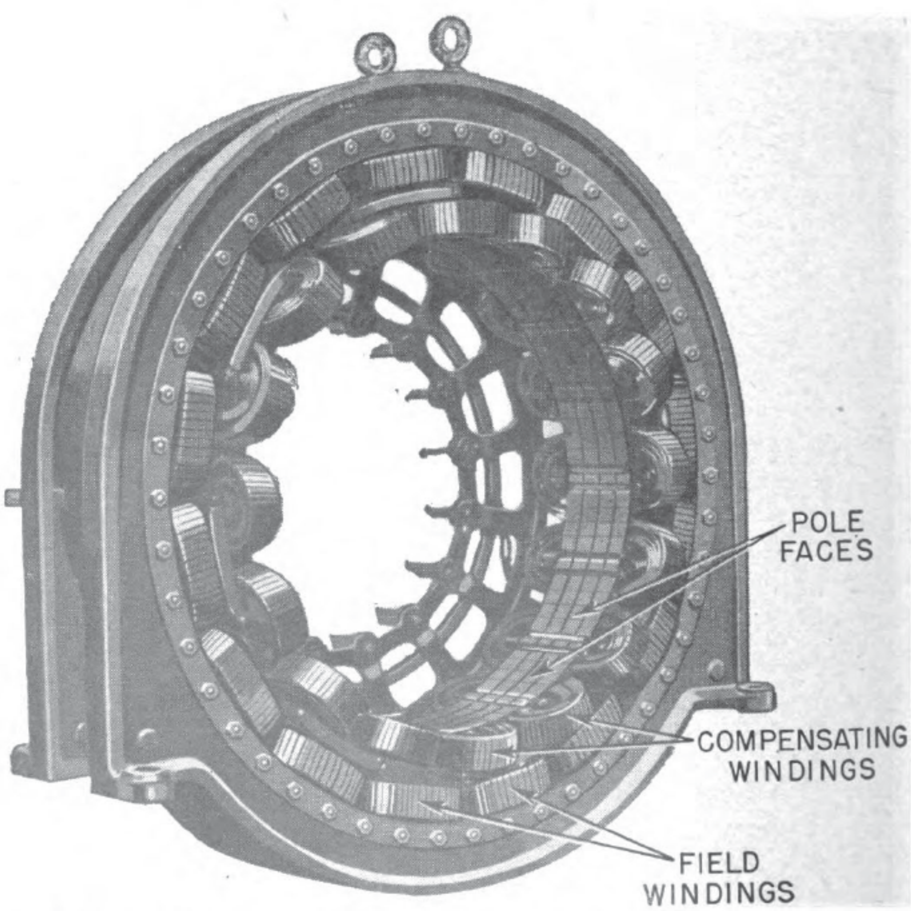


Figure 102.—Generator frame showing compensating windings.

armature current passes. This construction is illustrated in figure 102. The field poles and yoke are of a laminated

steel, and the compensating windings are the inboard set of coils.

Thus three methods of obtaining sparkless commutation are provided for all generator loads—by shifting the brushes, by using interpoles, and by using compensating windings. There are other methods but they will not be discussed at this time. If you wish to know more refer to the EM2 Training Course.

QUIZ

1. Complete the following statements:
   (a) The graph which shows the operation of a generator (change in voltage with change of current output) is called a generator ______.
   (b) The generator characteristic curve for a separately excited generator slopes ______ as generator load increases.
   (c) The auxiliary generator which supplies field current for a separately excited generator is called an ______.
2. Separately excited generators have widest application in what type of Navy equipment?
3. Name the three types of self-excited generators.
4. In all three types of self-excited generators, where is the field current taken from?
5. Complete the following statements:
   (a) In a series generator the field is connected ---- - with the armature.
   (b) In a shunt generator the field is connected ______ with the armature.
   (c) The compound generator has one field connected ______ and another field ______ the armature.
6. Why is the field of a shunt generator of relatively high resistance?
7. Why is the field of a series generator of very low resistance?

8. Complete the following statements:
   (a) When generator build-up starts, field flux is provided by ------.
   (b) In generator build-up, each increase in generator output voltage further ------ the generator voltage.
   (c) Generator build-up may be prevented by:
      1. ------ residual magnetism.
      2. ------ shunt field resistance.
      3. ------ shunt field connections.
      4. ------ shunt field circuit.
   (d) The output voltage of a shunt generator remains essentially ------ with increase of load.
   (e) The build-up of a shunt generator stops when the magnetic circuit becomes ------.
   (f) The field current in a shunt generator can be controlled by changing the ------ in the field circuit.
   (g) Changes of generator output voltage that occur automatically, due to the load changes, constitute voltage ------.
   (h) Voltage regulation is expressed in ------.
   (i) Percent voltage regulation may be found by the formula % regulation = ------.
   (j) Large voltage regulation has the following bad effects:
      1. ------ lamps supplied by generator.
      2. ------ motors supplied by the generator.
9. The output voltage of a generator when operating at no load is 240 volts, and at full load is 230 volts. What is the percent voltage regulation?
10. Complete the following statements:
   (a) A compound generator with a series field wound so it helps the shunt field is ------ compounded.
   (b) A compound generator with a series field wound so it opposes the shunt field is ------ compounded.
   (c) A compound generator which produces the same output voltage at no load as at full load is ------ compounded.
   (d) A compound generator which produces greater output voltage at full load than at no load is ------ compounded.

(e) A compound generator which produces smaller output voltage at full load than at no load is ------ compounded.

(f) The output voltage of a compound generator is controlled by changing the ------ in the shunt field circuit.

(g) The amount of compounding in a compound generator is controlled by changing the ------ across the series field.

(h) The formula for over-compounding of a compound generator is 0/0 over compounding= ------.

11. A compound generator has 240 volts output voltage at full load and 230 volts at no load. What is the percent over compounding?

12. Complete these statements:

(a) The output voltage of a series generator changes rapidly with changes in ------ of the external circuit.

(b) In a three-wire generator, a neutral wire is connected to the voltage ------ between both output terminals.

(c) In a 3-wire generator, a load connected between neutral wire and one of the outside armature leads gets ------ the full generator output voltage.

(d) Motor loads are connected across the ------ output of a 3-wire generator.

(e) A 3-wire generator is used because transmitting power to motor loads at higher voltage and lower current ------ the power loss in transmitting line.

(f) In a 3-wire system, if the loads connected from neutral to each armature terminal (loads connected on both sides of the line) are equal, ------ current flows in the neutral wire.

(g) In a 3-wire system, if the loads connected across the two sides of the line are not equal, the difference between the currents in the two sides of the line flows in the ------ wire.

(h) Using a 3-wire system to distribute electrical power permits a large saving in ------.

(i) If the two sides of a 3-wire system have unequal lamp loads, the lamp in one of these loads will be damaged by ------ voltage.

13. Complete the following statements:

(a) The position of the armature at which an armature coil has zero induced voltage is called the ------ plane.

(b) The magnetic flux due to the current in the armature conductors is called the ------ flux.

(c) When a generator armature rotates the field flux is crowded by the armature flux in the direction of ------.

(d) In a generator, arcing between brushes and the commutator will occur if brushes are not set at the ------ plane.

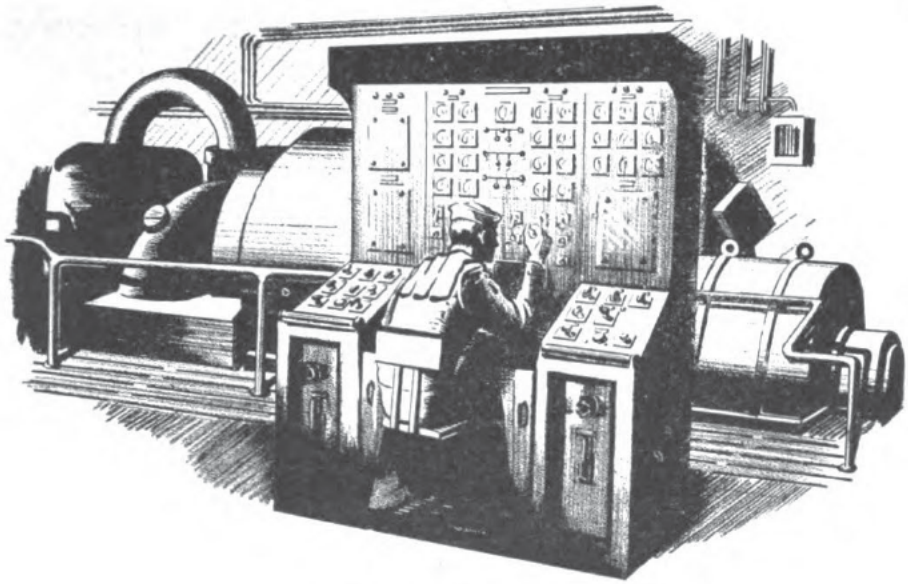
(e) The position to which the neutral plane is shifted by armature reaction depends on the armature ------.

(f) To prevent generator brush sparking due to armature reaction, brushes should be shifted to the neutral plane ------ produced by the armature reaction.

(g) Shift of neutral plane by armature reaction can be prevented by placing ------ between the main poles of the generator.

(h) To prevent armature reaction shift of the neutral plane at all loads, the interpole windings should carry the same current as the ------.

(i) When armature reaction is corrected by compensating windings these windings should be placed in slots in the field ------.



CHAPTER 8

OPERATION OF DIRECT-CURRENT GENERATORS

SHIPBOARD GENERATORS

Ships of the Navy have a great amount of electrical equipment. The largest source of current necessary to run this equipment is obtained from the ship's main generators, usually located in the machinery spaces. The number of generators varies from two to eight. The larger ships have two or more main switchboards for controlling the flow of current from these generators. The main switchboard, in turn, supplies current to all the various circuits about the ship.

The total current available from all the generators has to be enough to supply ALL electrical equipment that might possibly be used at any one time. The greatest demand for electric power is during battle conditions, when it is conceivable that every piece of electrical equipment might be in use. In addition, there must be a reserve of current available as a safety factor, in case one or more of the generators is disabled.

You say, "Why not install one great big generator in the ship to take care of all possible demands for current, and let it go at that?" You must remember that ships aren't always in battle conditions and the usual electrical demands

are not nearly as great, especially while at anchor. A generator is operating at its greatest efficiency when it is generating its full rated current output, so if only one large generator were installed then most of the time it would be running inefficiently, with only a part load.

PARALLEL OPERATION OF GENERATORS

So you will find ships equipped with more than one generator, and you run only enough of them in parallel to supply the current demands, without overloading any of the generators. With two generators operating in parallel, you are able to obtain the current output equal to the sum of the two outputs and at the voltage of one machine. The same is true for three generators in parallel operation—three times the current output of one generator is available at the voltage of one generator. Here is an example: Three generators are installed aboard your ship, each has a rating of 1,000 amperes at 230 volts. If the three are connected in parallel, you can obtain a total current output of 3,000 amperes at 230 volts.

Parallel operation of generators thus makes for a flexible arrangement. You operate just enough generators in parallel to furnish the total current demanded by the equipment that is running, yet you do not overoad any one of the generators. If the electrical load goes down enough to allow you to use one less generator, you cut one generator off the line and secure it. If the electrical load increases, you start up another generator and connect it to the line.

The current demand changes greatly during a 24-hour period aboard ship. Thus, an electrician's mate will be called upon many, many times to either parallel or secure generators. Soon after you are rated EM3, you will be expected to take over the watch at a main switchboard. The steps used in paralleling and securing d-c generators are of great importance and are listed in the following pages. Some of the steps may be omitted or others added as required by the particular installations aboard your ship, but the steps as listed here will cover the installations aboard most ships.

BEFORE YOU START, THINK OF THIS

Before you can parallel generators there are several points you must think of or you will get into a lot of trouble. First, ALL the generators must be able to produce the voltage at which the generators are to operate. It is preferable, but not absolutely necessary, that the current rating of the generators be equal, but it is necessary that ALL be of the SAME TYPE (shunt or compound), and ALL have the SAME VOLTAGE CHARACTERISTICS.

ENERGIZING A DEAD SWITCHBOARD

You will find it necessary to energize a dead switchboard when shifting from shore power to ship's generators near the end of a Navy Yard overhaul period, during which time the power was supplied to the ship from the Navy Yard powerhouse; or in cases where you have a total loss of power from the ship's generators to switchboards.

ENERGIZING A SWITCHBOARD—SHIFTING FROM SHORE POWER TO SHIP'S GENERATORS

NOTE the TOTAL ELECTRICAL LOAD that the ship's equipment is drawing from the generators ashore.

INSPECT ALL GENERATORS that are to be run, making sure they are all ready to be run and carry a load.

Have the machinist's mate BRING UP enough GENERATORS TO PROPER SPEED to carry the electrical load you just noted.

When machinist's mate indicates the generators are ready to take a load, STANDBY TO TRIP OUT SHORE POWER to the main switchboards AND to CUT IN the SHIP'S GENERATORS to the main switchboards.

TRIP OUT SHORE-POWER circuit-breaker. IF ONLY A SWITCH IS PROVIDED, DE-ENERGIZE ALL CIRCUITS AT SWITCHBOARDS BEFORE OPENING SWITCH. To do this follow procedure in this chapter for DE-ENERGIZING of SWITCHBOARDS

TRIP OUT CIRCUIT-BREAKERS (or open switches) AT each DISTRIBUTION SWITCHBOARD for most circuits supplied by the switchboard. This will prevent a large surge of current

being drawn when the first generator is put on the generator bus.

CLOSE THE MAIN CIRCUIT BREAKER (and line switch, if provided) OF ONE ship's GENERATOR.

GRADUALLY CUT IN some of the MOST VITAL CIRCUITS at the switchboards, making sure you DO NOT OVERLOAD THE one GENERATOR that is now on the bus.

If two or MORE GENERATORS ARE NEEDED to supply the electrical load of the ship, PARALLEL the ADDITIONAL GENERATORS required according to the steps listed in this chapter.

GRADUALLY CUT IN ALL REMAINING CIRCUITS at the switchboards as soon as the load can be carried safely by the generators on the line.

ENTER THE TIME OF all PARALLELING, and NUMBER OF all the GENERATORS involved, ON THE LOG sheet provided at the switchboard.

ENERGIZING A DEAD SWITCHBOARD—STARTING UP AFTER A TOTAL LOSS OF POWER FROM SHIP'S GENERATORS.

If the LOAD has been CARRIED BY ONE GENERATOR, immediately CUT running GENERATOR IN on the bus AGAIN, PROVIDED it is UP TO THE PROPER SPEED and able to carry a load.

If the LOAD has been CARRIED BY TWO or more GENERATORS, OPEN ENOUGH CIRCUITS at switchboards so ONE GENERATOR WILL NOT BE OVERLOADED more than 50% of rated load. Next, CUT ONE GENERATOR IN on the bus. Then PARALLEL ENOUGH GENERATORS, by following the steps listed in paralleling procedure given in this chapter, TO CARRY the TOTAL electrical LOAD. Finally, GRADUALLY CUT IN ALL CIRCUITS at the switchboards as soon as the load can be carried safely by the generators on the line.

PARALLELING D-C SHUNT GENERATORS

REMOVE canvas COVER from generator. INSPECT GENERATOR and make sure it is ready for operation. Be sure to look for, and to remove, tools, rags, and any thing else that may have been left in or on the generator.

Tell the MACHINIST'S MATE to BRING ONCOMING GENERATOR UP TO correct SPEED.

While the machinist's mate is bringing the generator up to speed, CHECK OVER your SWITCHBOARD to MAKE SURE ALL SWITCHES AND circuit BREAKERS FOR the ONCOMING GENERATOR ARE OPEN. Also, BE SURE that ALL RESISTANCE is CUT INTO its SHUNT FIELD (shunt field rheostat is turned to full "Lower" position).

TURN OFF generator HEATERS, if provided.

CHECK the VOLTAGE OF the generator BUS. If the voltage on the bus is not correct, adjust the field rheostat of the operating machine until the bus voltage is correct.

WHEN the machinist's mate reports the ONCOMING GENERATOR IS UP TO SPEED and that the prime mover is ready to take a load, CUT OUT FIELD RESISTANCE in the oncoming generator, UNTIL the VOLTAGE across the terminals OF the oncoming GENERATOR IS about 3 to 5 volts HIGHER THAN the BUS VOLTAGE.

CLOSE the circuit BREAKER (and line switch, if provided) of ONCOMING GENERATOR.

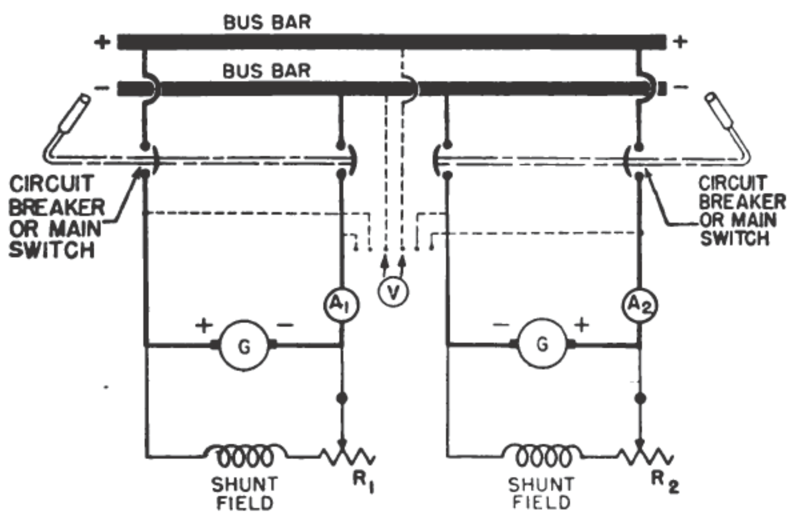


Figure 103.—Connection of shunt generators in parallel.

Immediately DIVIDE the TOTAL LOAD BETWEEN the paralleled GENERATORS by proper manipulation of their field rheostats—cutting OUT field resistance in oncoming generator, and cutting IN field resistance in machine which was on the bus before last operation of paralleling.

ENTER the TIME OF PARALLELING, and the NUMBER OF the GENERATOR, ON the LOG sheet provided at the switchboard.

SECURING D-C SHUNT GENERATORS

BEFORE SECURING a generator, MAKE SURE that the REMAINING GENERATORS to be left on the bus CAN CARRY the TOTAL electrical LOAD safely (without overload).

REDUCE LOAD ON OUTGOING GENERATOR (generator being secured) and SHIFT LOAD TO OTHER GENERATORS, by MANIPULATING FIELD RHEOSTATS of all generators on the bus UNTIL the GENERATOR which is BEING SECURED IS CARRYING a load of only 5 amperes (for smaller-capacity generators) TO 50 AMPERES (for larger-capacity generators). *CAUTION:* DO NOT RUN THE AMPERAGE ON THE OUTGOING GENERATOR DOWN TO ZERO BECAUSE OF DANGER OF SUDDEN REVERSAL OF CURRENT IN THAT GENERATOR FROM THE BUS.

TRIP circuit-BREAKER (and open line switch, if provided) FOR the GENERATOR that is TO BE SECURED.

CUT IN its entire FIELD RESISTANCE by turning rheostat OF SECURED MACHINE to full "Lower" position.

By manipulating field rheostats, ADJUST REMAINING GENERATORS on the bus TO operate at the CORRECT VOLTAGE.

If more than one generator is left on the bus, ADJUST rheostats for ALL GENERATORS still ON THE BUS SO that EACH IS CARRYING ITS SHARE OF the TOTAL LOAD AT PROPER VOLTAGE.

Notify machinist's mate that he may SECURE PRIME MOVER OF SECURED GENERATOR.

ENTER ON the LOG sheet provided at the switchboard the TIME OF SECURING, and the NUMBER OF the GENERATOR SECURED.

TURN ON generator HEATERS, if provided.

Using DRY, compressed AIR, BLOW OUT the WINDINGS OF the SECURED GENERATOR as soon as practicable.

Put canvas COVER over SECURED GENERATOR.

DE-ENERGIZING OF SWITCHBOARDS

De-energizing of switchboards is necessary only on rare occasions, as when switching over to shore power.

CUT OUT CIRCUITS at the switchboards UNTIL TOTAL LOAD IS below 50% OF RATED load OUTPUT OF ONE GENERATOR.

SHIFT ship's ENTIRE electrical LOAD TO ONE GENERATOR by securing other generators on the bus.

TRIP out the circuit-BREAKER OF the GENERATOR WITH the LOAD.

PARALLEL OPERATION OF COMPOUND GENERATORS

The first part of this chapter discussed shunt generators. The rest of this chapter will be devoted to compound generators. It might be stated here that the procedure listed above for energizing and de-energizing switchboards is applicable for switchboards that are supplied power by compound generators as well as shunt generators.

The principal fact to bear in mind in paralleling and securing compound generators is that you have an EQUAL-

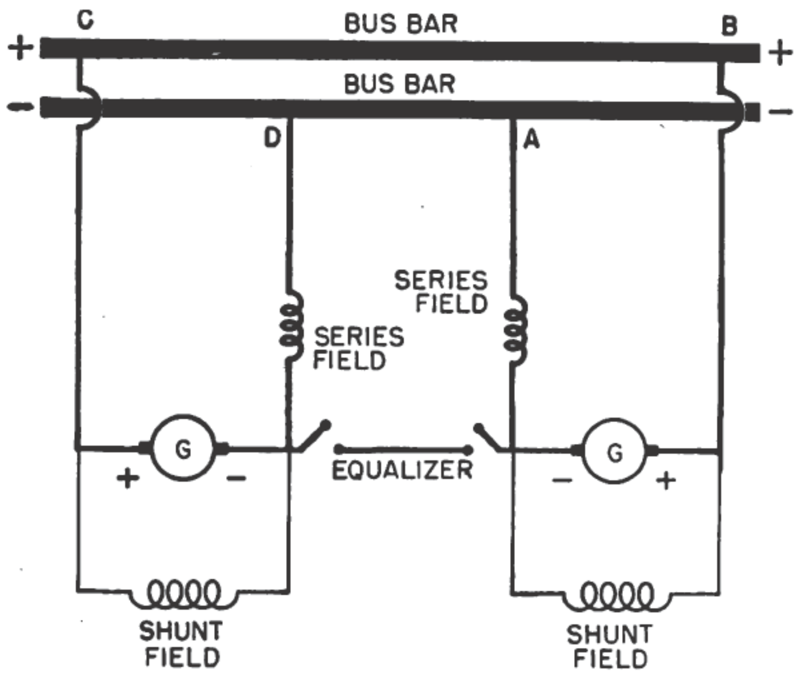


Figure 104A.—Connection of compound generators in parallel without equalizer.

IZER BAR in the circuit of parallel-connected compound generators, which is not present in parallel-connected shunt generators. This "bar," figure 104B, is a low-resistance bus-bar or cable which serves to connect the series fields of the

compound generators in parallel. This connection EQUALIZES THE AMOUNT OF CURRENT FLOWING THROUGH THE TWO SERIES FIELDS.

EQUALIZER BAR— A TRICK FOR TAMING WILD GENERATORS

The equalizing bar is necessary because, as soon as two compound generators are connected in parallel, an automatic shifting of the load from one generator to the other is started. This shifting process keeps on until one generator carries all the load and the other generator carries none. The equalizer prevents this "runaway" action and keeps each compound generator carrying its proper share of the load. Here is how the equalizer works.

Consider two compound generators hooked in parallel to the same line, WITHOUT an equalizer, as shown in figure 104A. Suppose each generator is taking ½ the load. An increase of load on the line will cause each generator to have increased series field current, hence an increased flux and increased voltage output. Due to slight differences in field resistance, iron saturation, etc., in the two machines, this voltage increase will not be the same for both generators. A small voltage difference will then exist between the two generators. This small voltage will, in effect, be acting across the very low resistance circuit formed by the armatures and series fields of both generators. (Circuit A-B-C-D, figure 104A.) This small voltage difference will therefore produce a heavy CIRCULATING CURRENT, i, through the series fields of both generators. As shown in figure 104B, this circulating current helps out (increases) the series field current of one generator, but opposes (cuts down) the series field current of the other. The generator with the increased series field current will then develop a still higher output voltage, and the one with decreased field current a still lower voltage. Thus, once a slight difference in voltage between both generators is produced, the difference automatically increases, and this process goes on until the voltage on one generator is decreased to zero and it carries NO LOAD, while the voltage on the other generator increases till it carries the ENTIRE LOAD. The

danger in this condition is that the generator taking the entire line load becomes overloaded, its breaker trips, cutting it off the line, and much of the ships electrical supply is shut off.

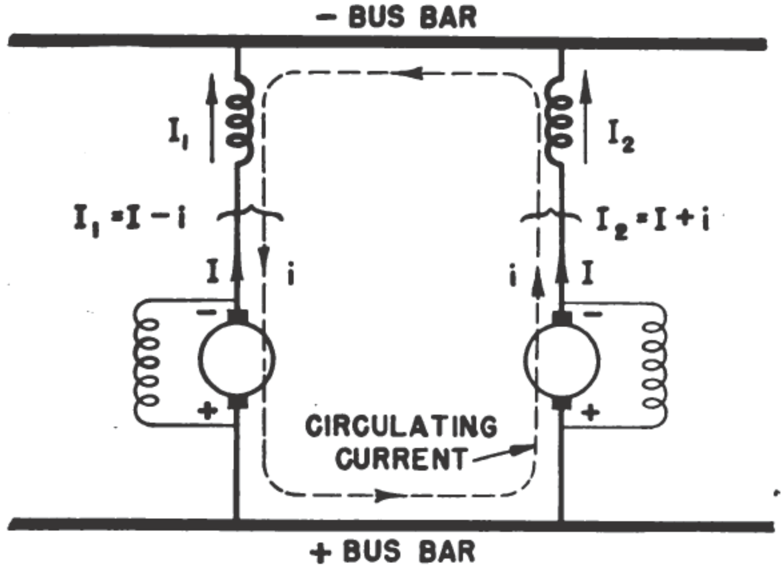


Figure 104B.—Currents in compound generators connected in parallel withou equalizer.

With a low resistance equalizer connecting the armature ends of both series fields, as shown in figure 104C, any circulating current will flow through the equalizer and thus be diverted from the series fields. The two generators will

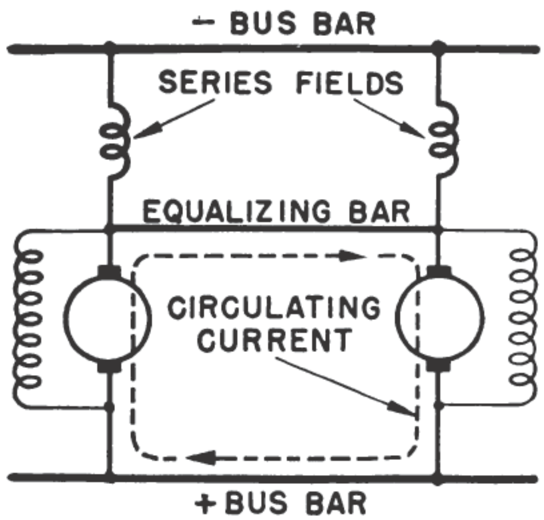


Figure 104C.—Currents in compound generators connected in parallel with equalizer.

therefore remain stable, each carrying its correct share of the load.

You can see from this explanation that the paralleling of compound generators is the same as for shunt generators, but THE EQUALIZER MUST BE CONNECTED FIRST before an additional compound generator is connected to the line. Compound generator switchboards therefore have an EQUALIZER BUS with a knife switch to connect each generator to this bus. See figure 104D.

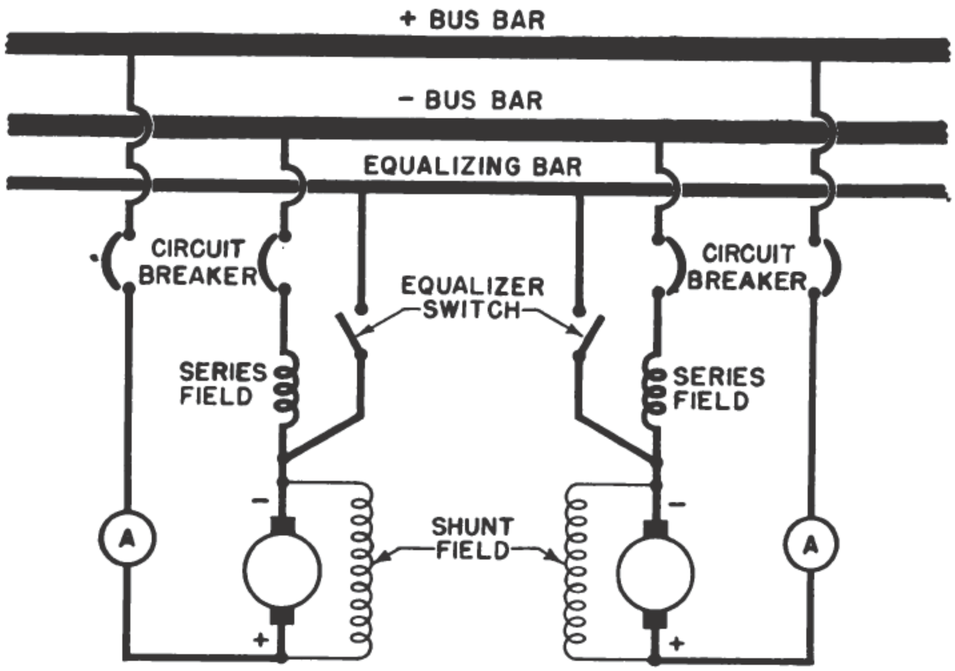


Figure 104D.—Switchboard connections, compound generators connected in parallel.

PARALLELING D-C COMPOUND GENERATORS

REMOVE canvas COVER FROM the GENERATOR.

INSPECT THE GENERATOR and make sure it is ready for operation. Be sure to remove all tools, rags, and other materials that may have been left in or on the generator.

Notify the Machinist's Mate to BRING the oncoming generator's PRIME MOVER UP TO correct SPEED.

WHILE the Machinist's Mate is BRINGING the GENERATOR UP TO SPEED, CHECK over your switchboard to make certain THAT the CIRCUIT-BREAKER, LINE SWITCH and EQUALIZER

SWITCH for the incoming generator ARE OPEN. Also, BE SURE that ALL RESISTANCE IS CUT INTO the SHUNT FIELD (shunt field rheostat is turned to full "Lower" position).

TURN OFF the generator HEATERS, if provided.

CHECK the VOLTAGE OF the generator BUS. If the voltage on the bus is not correct, adjust the rheostat of the generators with the load until the bus voltages are correct.

WHEN the machinist's mate reports that the ONCOMING GENERATOR IS UP TO SPEED and that the prime mover is ready to take a load, CUT OUT FIELD RESISTANCE in the oncoming generator, UNTIL the VOLTAGE across the terminals OF the ONCOMING GENERATOR IS about 3 to 5 volts HIGHER THAN THE BUS voltage.

CLOSE the circuit-BREAKER of the ONCOMING GENERATOR.

CLOSE the EQUALIZER SWITCHES of BOTH generators.

CLOSE the COMMON NEGATIVE SWITCH. The load current now divides between the two series fields. ADJUST the VOLTAGE OF BOTH GENERATORS TO correct BUS VOLTAGE by manipulating the field rheostats.

CLOSE POSITIVE SWITCH.

Immediately DIVIDE the total LOAD BETWEEN paralleled GENERATORS by manipulating field rheostats of all generators on the bus. That means—cutting out field resistance in the oncoming generator and cutting in field resistance in the generators on the bus before paralleling.

ENTER ON the LOG sheet provided at the switchboard the TIME OF PARALLELING, and the NUMBER OF the GENERATOR.

SECURING D-C COMPOUND GENERATORS

BEFORE SECURING a generator, MAKE SURE that the GENERATOR (or generators) to be left ON the BUS CAN CARRY safely the total electrical LOAD without overloading.

Manipulate the field rheostats of generators on the bus so as to REDUCE the LOAD ON the GENERATOR TO BE SECURED, and distribute it to other generators UNTIL the GENERATOR TO BE SECURED IS CARRYING ONLY 5 AMPERES (for smaller-capacity generators) TO 50 AMPERES (for larger-capacity generators) load. *CAUTION:* DO NOT RUN THE AMPERAGE ON THE OUTGOING GENERATOR DOWN TO ZERO because

of the danger of sudden reversal of current in that generator from the bus.

TRIP the circuit-BREAKER FOR the GENERATOR that is TO BE SECURED.

OPEN first its POSITIVE SWITCH and THEN its NEGATIVE SWITCH.

OPEN THE EQUALIZER SWITCHES of both generators, if only two have been paralleled; otherwise OPEN the EQUALIZER SWITCH TO the GENERATOR BEING SECURED.

TURN THE SECURED GENERATOR FIELD RHEOSTAT TO full "LOWER" position.

ADJUST REMAINING GENERATOR (or generators) on the bus TO operate at CORRECT VOLTAGE.

If more than one generator is left on the bus, ADJUST RHEOSTATS for generators UNTIL EACH GENERATOR IS CARRYING ITS SHARE OF the total LOAD at proper voltage.

NOTIFY the MACHINIST'S MATE that the PRIME MOVER of the secured generator MAY BE SECURED.

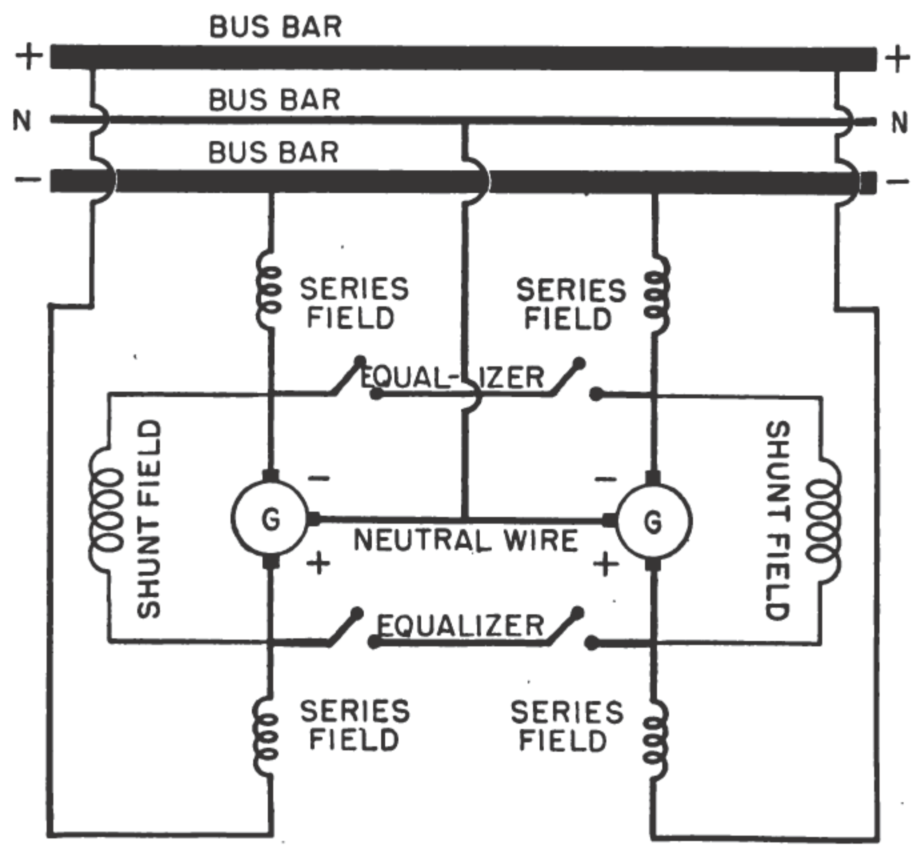


Figure 105.—3-Wire generators connected in parallel.

ENTER the TIME OF SECURING, and the NUMBER OF the GENERATOR secured ON the LOG sheet provided at the switchboard.

TURN ON HEATERS for secured generator, if provided.

Using DRY compressed AIR, BLOW OUT the WINDINGS OF the SECURED GENERATOR as soon as practicable.

Put canvas COVER over SECURED GENERATOR.

PARALLELING OF THREE-WIRE GENERATORS

In connecting two 3-wire generators in parallel, two equalizers are needed, one for each half of the series field of a generator. The steps for the paralleling and securing of this type of generator are the same as listed for paralleling and securing compound generators. A diagram showing the connection of two paralleled, 3-wire generators is shown in figure 105.

SAFETY PRECAUTIONS FOR GENERAL WATCH-STANDERS

No READING or horse-play allowed WHILE ON WATCH.

No ONE except authorized personnel shall go BEHIND MAIN SWITCHBOARDS.

No UNNECESSARY GEAR shall be allowed to accumulate AROUND SWITCHBOARDS OR GENERATORS.

No UNAUTHORIZED PERSONNEL shall loiter ON YOUR STATION.

CONSULT the list of SAFETY RULES your station or electrical officer has posted at the switchboards. OBSERVE ALL without fail.

DUTIES OF A WATCH-STANDER AT GENERATORS AND SWITCHBOARD

INSPECT ALL RUNNING GENERATORS frequently. REPORT any TROUBLES TO the responsible EMC OR the ELECTRICAL OFFICER.

Keep CORRECT share of LOAD ON EACH GENERATOR that is paralleled on the bus.

KEEP the LOG sheet UP TO DATE with the required hourly readings.

KEEP GENERATORS, SWITCHBOARDS AND ADJACENT AREA CLEAN and swept down.

AFTER a GENERATOR IS SECURED, BLOW OUT the commutator, armature and field windings WITH DRY compressed AIR.

NEVER REPLACE a blown FUSE WITH one of a HIGHER CAPACITY.

SET ALL circuit BREAKERS TO TRIP AT PROPER LOAD and ALLOW NO ONE TO CHANGE the SETTING.

REPORT ALL GROUNDS indicated on ground-detector lamps to a responsible person.

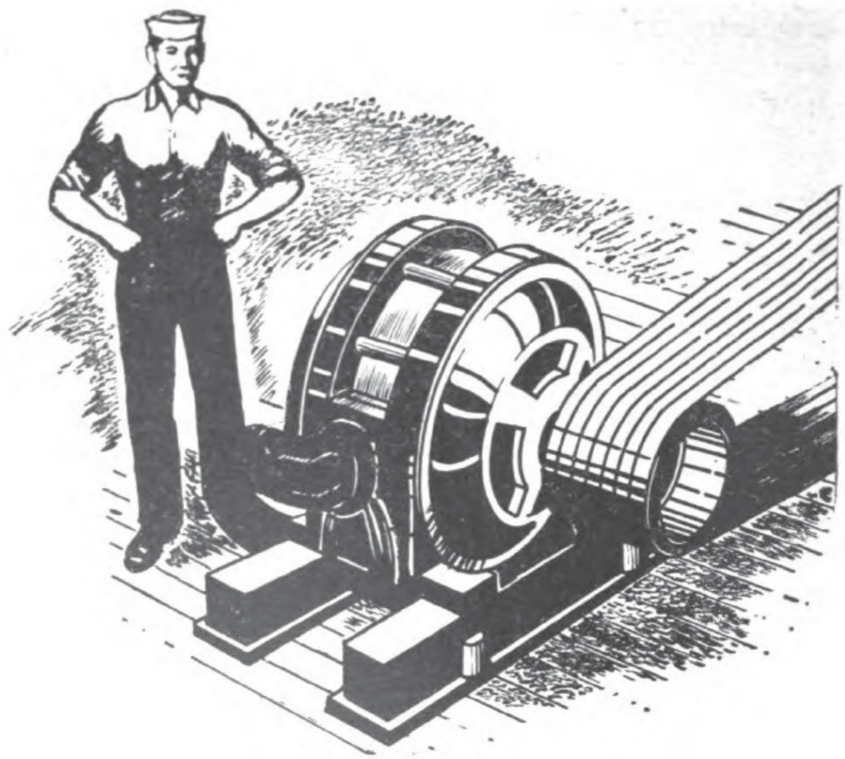
DO NOT ALLOW EMERY CLOTH OR STEEL WOOL to BE USED NEAR any ELECTRICAL EQUIPMENT.

CONSULT a LIST OF DUTIES to be performed WHILE ON WATCH. This list usually is posted at the switchboard.

QUIZ

1. Complete the following statements:
   (a) Current flow from the ship's generators to the various circuits is controlled by the main ______.
   (b) The greatest demand for electrical power exists aboard ship during ______.
2. Why is the power required by a ship generated by smaller generators connected in parallel than by one big generator?
3. Complete these statements:
   (a) When generators are connected in parallel, the line current is the ______ of their current outputs.
   (b) When generators are connected in parallel, the line voltage is the same as the voltage output of ______ machine.
   (c) In parallel operation of generators, if load increases generators are ______ ______ the line.
   (d) In parallel operation of generators, if load decreases generators are ______ ______ the line.
   (e) All generators to be operated in parallel must be of the ______ type.
   (f) All generators to be operated in parallel must have the same ______ characteristics.
4. Name the two occasions when a dead switchboard may have to be energized.
5. Name the eleven steps required to energize a dead switchboard when shifting from shore to ship power.

6. Name the five steps required to energize a main switchboard after total loss of power from generators.
7. Name the nine steps for paralleling d-c shunt generators.
8. Name the eleven steps required in securing a d-c generator.
9. In securing a shunt generator, what is the danger in running the current output of the shunt generator down to zero?
10. Name the three steps required in de-energizing a main switchboard.
11. Why is an equalizer bar necessary when paralleling two compound generators?
12. Complete the following statements:
    (a) An equalizer bar is a low resistance tie line that connects the ------ fields of two compound generators connected in parallel.
    (b) A circulating current flows through the series fields of two compound generators connected in parallel if the generator voltages are ------.
    (c) When a circulating current flows in the series fields of two compound generators connected in parallel it will:
        1. ------ the voltage of the lower voltage generator.
        2. ------ the voltage of the higher voltage generator.
    (d) The shift of output voltages of two compound generators in parallel produced by the circulating current continues automatically until:
        1. The generator losing voltage carries ------ load.
        2. The generator gaining voltage carries ------ load.
13. What dangerous operating conditions results from automatic load shift between two paralleled compound generators?
14. Name the thirteen steps required to parallel compound generators.
15. Name the thirteen steps required to secure d-c compound generators.
16. How does paralleling of 3-wire compound generators differ from paralleling two-wire d-c compound generators?
17. Name the five safety precautions which must be observed by the Electrician's Mate on Watch.
18. Name the nine duties of watch standers at generators or switchboard.



CHAPTER 9

DIRECT-CURRENT MOTORS

INTRODUCTION

A direct current generator is a machine which converts mechanical energy into electrical energy. The mechanical energy is supplied by a steam turbine or a Diesel engine; the electrical energy is fed out through the brushes into the line. This machine is reversible. If you feed electric current into it, it will operate as a motor and will drive a mechanical load. A d-c motor is thus a d-c generator operated in reverse.

MOTOR CONSTRUCTION

The d-c motor therefore has the same parts, and is constructed in the same manner as the d-c generator, with a stationary field winding, a rotating armature, a commutator and brushes. But due to their different uses, the construc-

tion of motors and generators may differ in certain practical details. Thus the generator is usually located next to the prime mover, so it is usually mounted on a horizontal base. Motors, on the other hand, are mounted in overhead, vertical, or in any other position that is most convenient for driving the load. Also, because they may be located in exposed positions and in moist or dusty compartments, motors and generators are generally totally enclosed; in some cases the enclosure may even be water tight. Such a tightly enclosed machine will run very hot, so provision is usually made for air cooling. Hence you will generally find a cooling fan on the shaft and cooling ducts in the frame through which this fan circulates the cooling air.

PRINCIPLE OF A MOTOR

Figure 106A shows a uniform field between the opposite poles of two magnets. Figure 106B represents the cross-

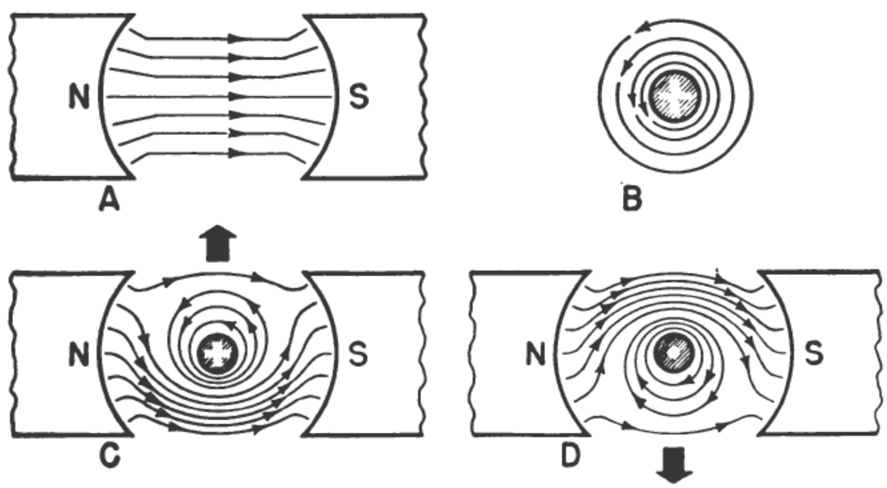


Figure 106.—Principle of electric motor.

section of a conductor placed between two poles and carrying current away from the observer. Assume the field due to the north and south poles has been temporarily removed. By applying the left hand rule for a current-carrying conductor, you will find the lines of force around the conductor to be in counter-clockwise direction.

Now suppose the conductor of figure 106B is placed in the magnetic field of figure 106A. The resultant magnetic field will be as shown in figure 106C. Above the conductor, the

field is weakened because the two fields are opposite in direction and tend to cancel each other. Below the conductor, the fields add because they are in the same direction. Since magnetic lines of force act to push each other apart, those below the conductor tend to push it up, and those above the conductor act to push it down. But the field below is much stronger, having many more lines, so the push upward is greater, with the result that the conductor in figure 106C is moved upward. If the current in the conductor is reversed, as shown in figure 106D, the direction of motion will be reversed because in this case the field above the conductor is strengthened while the field below is weakened.

Thus you have the principle on which the operation of an electric motor is based: A CONDUCTOR CARRYING CURRENT IN A MAGNETIC FIELD TENDS TO MOVE AT RIGHT ANGLES TO (ACROSS) THE FIELD.

MOTOR TORQUE

Now consider an actual motor. Each current-carrying conductor in the armature is in the form of a loop with two sides of the loop lying in a magnetic field, as shown in figure

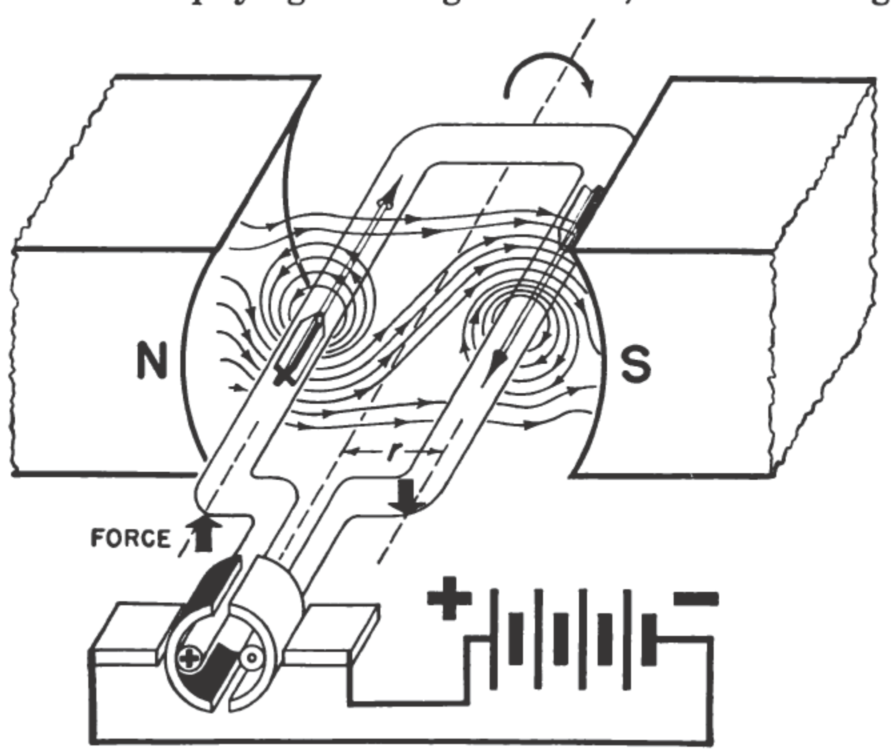


Figure 106E.—Motor torque.

106E. The force acting in one direction, on one side of the loop, and the force acting in the other direction, on the other side, combine to cause the coil to turn on its axis. The loop thus acts as if it were a lever with a turning force at each end. Due to this lever arrangement the force at each end is magnified by its distance from the center. As you learned in *Basic Machines*, the overall turning effect on the loop, called the TORQUE, is the combined force on the two sides of the loop times the distance of the conductors from the axis. Stated in a simple equation, this relation for the torque on each loop is—

$$\text{Torque} = \text{Force on conductor} \times \text{radius of loop}$$
$$T = F \times r$$

The torques on all the individual armature conductors add up to give you the total MOTOR TORQUE, which is measured in POUND-FEET. The greater the motor torque the more pull the motor has to drive a mechanical load. It is important to know about torque of electric motors because the same thing happens to an electric motor as happens to the engine of your car. If it does not have enough torque to pull the load, it stalls.

It has been determined by experiment that the force on a current-carrying conductor in a magnetic field is proportional to the field strength, to the active length of the conductor (length lying in the magnetic field), and to the current flowing through the conductor. The torque for the entire armature, or motor torque, is then dependent on the field flux, the armature current, and the dimensions of the armature and its conductors. This relation can be stated by the simple equation—

$$\text{Motor Torque} = K \times I_a \times \phi$$

Here the K stands for a fixed number (a constant) which depends on the design of the armature (its dimensions, number of conductors, etc.); I_a stands for the armature current; and ϕ represents the field flux. So if you want a motor to have more pull, or torque, you must increase either the armature current or the field flux. How these are done you will learn in later paragraphs.

FLEMING'S RIGHT HAND RULE FOR A MOTOR

There is a definite relation between the direction of the magnetic field, the direction of current in the conductor, and the direction in which the conductor tends to move. This

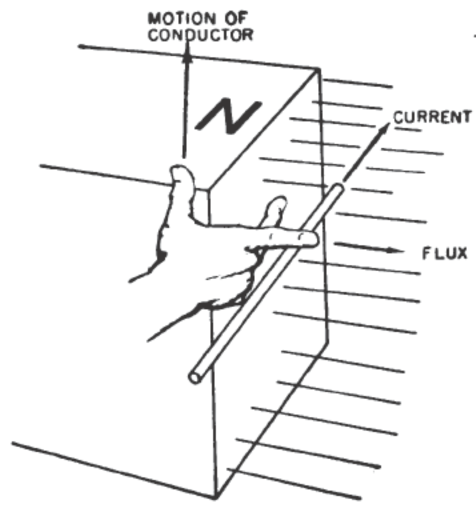


Figure 107.—Right hand rule for motors.

relation is expressed in Fleming's Right Hand Rule. It states:

> Place your RIGHT HAND in a position so the LINES OF FORCE from the north pole of the magnet ENTER THE PALM of the hand. Let the extended FINGERS point in the DIRECTION THE CURRENT in the conductor is flowing, then the THUMB, placed at right angles to the fingers, points in the DIRECTION OF MOTION of the conductor.

From this rule you can always determine the direction of rotation of a motor if you know the direction of the current.

LENZ'S LAW IN ELECTRIC MOTORS—COUNTER ELECTROMOTIVE FORCE

When any conductor cuts magnetic lines of force an emf is induced in it. This holds true for the conductors of a motor armature as it does for the conductors of a generator, because in both cases the conductors are rotating in a magnetic field.

In the chapter on induction (Ch. 4) you learned that this

induced emf always obeys Lenz's law. This law states:

The current produced by the induced emf will be in such a direction that its field will oppose the motion producing the induced emf.

Now to understand what this emf does in a motor consider a motor with a single-turn armature, as shown in figure 108. The line voltage, *E*, applied to the armature,

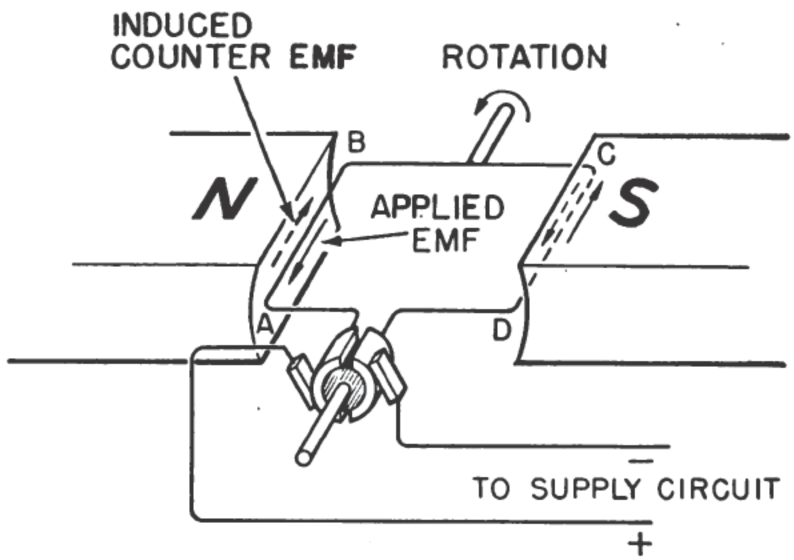


Figure 108.—Counter electromotive force in a motor.

produces a current which flows around the coil as shown by the solid arrow. This current starts the armature rotating. Immediately after rotation starts an induced emf is produced due to the armature conductors cutting the magnetic field. By Lenz's law this induced emf should produce a current in a direction to oppose the motion of the conductor. The left hand rule you learned in the chapter on Induction ties in the motion of a conductor with its current and the surrounding field. Using this rule on the conductor in figure 108, you see that the induced emf will tend to produce a current flow in the direction of the dotted arrow—that is, around the coil from *A* to *B* to *C* to *D*. This is in the direction OPPOSITE to the current flow produced by the line voltage applied to drive the motor. Thus THE EMF INDUCED IN A MOTOR ARMATURE, due to its rotation, OPPOSES, or bucks, THE APPLIED (LINE) VOLTAGE. The induced emf in a motor is therefore called a COUNTER ELECTROMOTIVE FORCE.

HOW MUCH COUNTER ELECTROMOTIVE FORCE?

How big will this counter electromotive force be? You learned in the chapter on Generators (Ch. 5) that when armature conductors cut lines of magnetic flux, the voltage induced in the armature is

$$E_c = K \times \Phi \times S$$

where K is a fixed number depending on the design details of the machine (length of armature conductors, their number, the number of poles, etc.); Φ is the flux from each pole; S is the speed of rotation of the armature. This formula tells you that THE COUNTER ELECTROMOTIVE FORCE (E_c) WILL BE PROPORTIONAL TO THE SPEED OF ROTATION (revolutions per minute) AND TO THE FIELD STRENGTH.

But how large can this counter electromotive force become? The line must supply a voltage to push through the armature's resistance the current which causes the motor to rotate. The voltage necessary to do this is called the ARMATURE RESISTANCE DROP. By Ohm's law, you know that for an armature current I_a and armature resistance R_a, the armature resistance drop is $I_a \times R_a$.

In addition to furnishing a voltage to overcome this resistance drop, the line voltage must supply a voltage to overcome the counter electomotive force (Ec). The line voltage (E_a) must therefore be the sum of the armature drop (I_aR_a) and the counter electromotive force (Ec). Or, saying it in an equation—

$$E_a = I_aR_a + E_c$$

This relation is very useful because it enables you to understand all phases of the operation of a d-c motor and to solve most motor problems.

EFFECT OF COUNTER ELECTROMOTIVE FORCE ON A MOTOR

The resistance of a d-c motor armature is usually small. Frequently it is much less than an ohm. So if the usual

line voltage (110 or 220 volts) should be applied to the armature, a huge current would flow, overheating and ruining the armature. Here's where the counter electromotive force (cemf) comes in handy. Since the cemf always opposes the line voltage, it cuts down the current which the line voltage can send through the armature. Hence the cemf is an automatic current limiter which cuts down the armature current to a reasonably safe value.

For example, suppose 230 volts are supplied to a 5-horsepower (5 hp) motor which runs at 850 revolutions per minute (850 rpm) when at full load, and at that speed has a cemf of 210 volts. The armature resistance of this size motor is about one ohm. According to Ohm's law, the armature current would be—

$$I_a = \frac{E_a}{R_a} = \frac{230}{1} = 230 \text{ amperes}$$

Such a high armature current would burn out the armature winding unless there is something besides armature resistance to limit the current. This limiting force is our cemf. At full load the cemf for this motor is 210 volts, and this voltage opposes the line voltage. So the voltage left to force a current through the armature is 230–210, or 20 volts. With 20 volts driving a current through a resistance of 1 ohm, the current is, by Ohm's law, $I_a = \frac{20}{1}$ or 20 amperes. That is a safe current for your armature windings.

STARTING RESISTANCES

Obviously when a motor armature is at rest the cemf developed is zero, but when the armature starts to turn it begins to induce a counter emf, and as it speeds up the counter emf increases. Resistances are therefore inserted in series with the armature to limit the current while the motor is being started. Once it is up to speed the cemf developed by the armature limits the current and the starting resistances are cut out. The device for switching resistances into the motor circuit is called a MOTOR STARTER or CONTROLLER.

When the motor is about to be started, the controller con-

nects all of the starting resistance in series with the armature. This resistance is great enough to limit the starting current to any desirable value. However, as the armature attains speed, the controller cuts out the resistance step by step, until all of the starting resistance is out of the circuit when the armature is running at the full speed at which it is designed to operate. The armature is then connected directly across the line. You will learn more about motor controllers in chapter 11.

CURRENT TAKEN BY A D-C MOTOR

In a gasoline engine you adjust the throttle to produce the right engine pull for each load. In a d-c electric motor the torque, or motor pull, depends on the armature current and the motor itself automatically adjusts this current to produce the right torque for each load.

Here is how it works: You learned earlier in this chapter that the armature current (I_a) which drives the motor is produced by the line voltage, E_a, overcoming the armature resistance drop (I_aR_a) and the counter electromotive force (E_c). That is, armature drop and cemf always add up to line voltage, or $E_a = I_aR_a + E_c$.

You also learned in earlier paragraphs that the torque depends on the armature current (I_a), and that the counter electromotive force (E_c) depends on the motor speed. Now suppose the motor is running with a light load. A small armature current will produce enough torque to drive the motor at high speed. Due to the small armature current the armature resistance drop (I_aR_a) is small; and due to the high speed the counter electromotive force (E_c) is large. Hence with a light load a large counter electromotive force (E_c), but small armature drop (I_aR_a), add up to E_a, because $E_a = I_aR_a + E_c$.

Suppose you now put a heavier load on the motor. The small armature current which has been flowing does not produce enough torque (pull) to drive the heavier load at high speed, so the motor starts to slow up. This reduces the counter electromotive force (E_c). You now have a smaller cemf to oppose the flow of current into the armature and the

armature current increases. This large current produces a larger torque which can pull the heavier load, and the motor stops slowing up. Therefore with a heavier load the motor adjusts itself to run at a new, lower speed. What will this speed be?

Now at the new lower speed the larger armature current produces a larger armature drop (I_aR_a), and the cemf E_c is smaller, due to the lower speed. But the line voltage E_a, furnished by the ship's power supply, does not change. So for the heavier load, $E_a = I_aR_a + E_c$ tells you that the new cemf (E_c) and the new armature drop (I_aR_a) must add up to the same E_a as before. From this you see that a D-C MOTOR ALWAYS TENDS TO RUN AT SUCH A SPEED THAT THE SUM OF THE ARMATURE RESISTANCE DROP (I_aR_a) AND THE COUNTER ELECTROMOTIVE FORCE (E_c) JUST EQUALS THE LINE VOLTAGE. It is in this way that a d-c motor automatically adjusts its own speed and torque so that, for a light load the current (torque) is small and speed is high; for a heavy load the current, hence torque, is higher and the speed is lower.

MOTOR SPEED

There are three ways to change the speed of a d-c motor. All three can be used to control motor speed. One way, as you just learned, is to change the motor load. As the LOAD INCREASES the SPEED DECREASES. Another way is to change the field flux (by changing the field current). When the FIELD FLUX INCREASES, motor SPEED DECREASES. The third way to change motor speed is to change the line voltage. When LINE VOLTAGE INCREASES motor SPEED also INCREASES.

You can understand how each of these methods works and the advantages of each by a glance back at the equation which tells you all that is going on in an electric motor—

$$E_a = I_aR_a + E_c$$

Here again E_a is the line voltage, I_a the armature current, and E_c the counter electromotive force. Remember that this equation means—

Line voltage = Armature resistance drop + counter electromotive force.

MOTOR SPEED CONTROL BY CHANGING MOTOR LOAD

Several paragraphs back you learned that the counter-electomotive force, E_c, depends on the speed of the armature (revolutions per minute) and on the field strength. This relation was simply expressed by the equation—

$$E_c = K \times \Phi \times S$$

Where K is a fixed number, Φ is the field flux, and S is the motor speed. Elementary algebra tells you that for E_c you can substitute its equal, $K \times \Phi \times S$, in the motor equation. Then—

$$E_a = I_a R_a + E_c \text{ becomes } E_a = I_a R_a + K \times \Phi \times S$$

You want to solve this equation for motor speed, S, so you subtract $I_a R_a$ from both sides, and get—

$$E_a - I_a R_a = K \times \Phi \times S$$

and, if you divide both sides of the equation by $K \times \Phi$, this boils down to—

$$\frac{E_a - I_a R_a}{K \times \Phi} = S$$

This is called the MOTOR SPEED EQUATION. Put into words, this equation tells you that—

$$\frac{\text{Line voltage} - \text{Armature resistance drop}}{\text{Constant} \times \text{Flux}} = \text{Motor Speed}$$

Consider a practical example. The motor in the example given earlier in this chapter operates on a line voltage of 230 volts; at full load it has a speed of 850 RPM, and draws a current of 20 amperes. The armature resistance is 1 ohm. So our speed equation is—

$$850 = \frac{230 - 20 \times 1}{K \times \Phi}$$

from which we find that $K \times \Phi = \frac{210}{850} = .247$

Now suppose the load is reduced 50% which cuts down the armature current 50% to 10 amperes. What is the new motor speed?

$$S=\frac{E_a-I_aR_a}{K\Phi}$$

so now—

$$S=\frac{230-10\times 1}{.247}$$

$$S=\frac{220}{.247}$$

$$S=890\ \text{RPM}$$

Thus, producing a big change in the load (fully 50%) produces a speed change of only 40 revolutions in 850, or about 4.7%. Therefore this is a poor method to use for controlling motor speed.

MOTOR SPEED CONTROL BY CHANGING FIELD

Now consider the second method of changing motor speed—by changing the field flux. To find out how much the speed changes when the field flux is changed, let us again try a practical example. A motor of the size used in the previous example usually has a field flux (flux per pole) of 1,000,000 lines. So using the speed equation, at full load—

$$850=\frac{230-20}{K\times 1{,}000{,}000}$$

and—

$$K=.247\ (10^{-6}).$$

Now let us change the flux 10%, reducing Φ to 900,000 lines. Then—

$$S=\frac{230-20}{K\times\Phi}$$

$$S=\frac{210}{.247\times 10^{-6}\times 900{,}000}$$

$$S=\frac{210}{.9\times .247}$$

$$S=943\text{ RPM}$$

Thus for a change of 10% in field flux you get a change in speed of 943−850=93 RPM in 850, or about 11%. You therefore get about as much change in speed as you have change of field flux. Hence this is a good method to use for control of motor speed. *CAUTION:* The SPEED GOES UP AS FLUX GOES DOWN, SO DO NOT OPEN THE FIELD CIRCUIT OF A MOTOR, BECAUSE this will leave only a small field flux, and the MOTOR SPEED WILL BECOME DANGEROUSLY HIGH.

MOTOR SPEED CONTROL BY CHANGING LINE VOLTAGE

Finally, there is the method of changing line voltage to change motor speed. Let us again take the 5 hp motor as an example. Suppose the motor is running at ½ of full load. That means the current is ½ of full load current, or 10 amperes. Then

$$S=\frac{230-10}{.247}=890\text{ RPM}$$

Suppose you change E_a by 10 volts, or 4.35%, raising it to 240 volts. Then—

$$S=\frac{240-10}{.247}$$

$$S=930\text{ RPM}$$

or a speed change of 40/850=4.7%.

Thus changing E_a is also a good method of motor speed control, because the change in motor speed is about as large as the change in line voltage. However, instead of changing the voltage of the line, the motor is usually connected in series with a resistor across the line. Changing this resistor then in effect changes the voltage (E_a) applied to the motor, and thus changes its speed.

MOTOR POWER

The electrical power taken by a d-c motor from the line is the product of the current and the voltage. That is—

$$\text{Power} = \text{Voltage} \times \text{Current}$$

$$P = E \times I$$

Not all of this power input comes out as useful mechanical work of driving the motor load. A small part of this power is used up in forcing a current through the motor's field winding; another small part goes into heating the armature, and still another part in overcoming the friction and windage (air resistance). These quantities of power are wasted, as far as getting mechanical work out of the motor is concerned, so are called LOSSES.

The bulk of the electrical power put into the motor comes out as mechanical power applied to the pulley or to the gear on the motor shaft. This mechanical power is proportional to the motor torque and speed, and is equal to the product of the two. (See *Basic Machines.*) That is—

$$\text{Power} = \text{Torque} \times \text{Speed}$$

$$P = T \times S$$

Where T is the torque, S is the motor speed, and P is the power output. This power output is the mechanical work done by the motor per minute, and is expressed in FOOT-POUNDS PER MINUTE.

You learned in *Basic Machines* that doing 33,000 foot-pounds of work per minute is equivalent to one horsepower. So the power output of a motor, in horsepower, is—

$$\frac{\text{Torque} \times \text{Speed (RPM)}}{33{,}000} = \text{Horsepower}$$

$$\frac{T \times S}{33{,}000} = \text{hp}$$

On the name plate of each motor are always marked the speed and horsepower of the motor at full load. Therefore using the above equation and the data of the name plate,

you can always find the torque, or pull, that the motor can produce at full load.

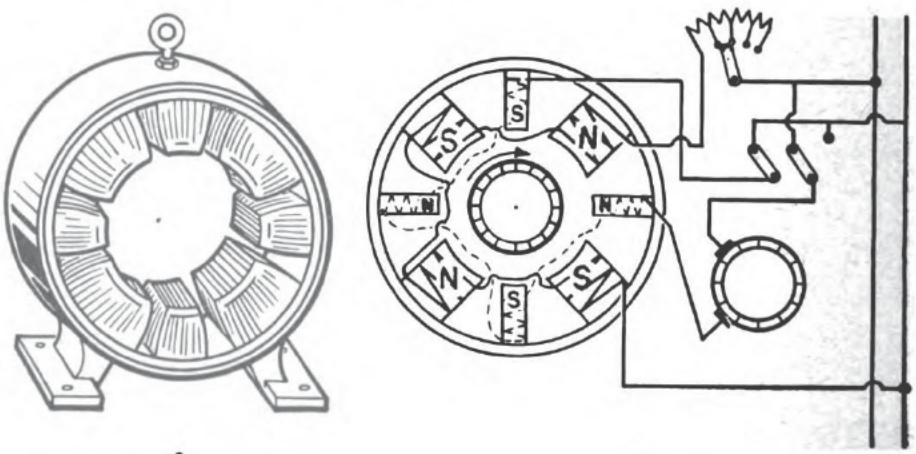
ARMATURE REACTION IN MOTORS

Since any generator will operate as a motor, it can be expected that armature reaction in a motor must be similar to armature reaction in a generator. However, current in a motor armature is in the opposite direction to the current in the armature of the same machine when it is operating as a generator. This causes motor armature reaction to be basically the same as generator armature action, but in the opposite direction. Thus, the same essential principles are involved as those explained in chapter 7 for generators, but the difference is that the armature flux distorts the main field so that the pole flux tends to bunch up at the LEADING tips of the pole pieces, instead of on the trailing tips.

Consequently, in a motor, armature reaction shifts the neutral plane (where no voltage is induced in the conductors) BACKWARD against rotation, instead of forward, as in a generator. The BRUSHES in a motor MUST therefore BE SHIFTED BACKWARD AGAINST ROTATION to a position where the highest speed with the least sparking is obtained.

CURING MOTOR ARMATURE REACTION—INTERPOLES

Since the motor and generator armature reaction effects are similar, they can be corrected in a motor by interpoles



A B

Figure 109.—D-C motor interpoles.

as they are in a generator. The motor interpoles are mechanically the same as in a generator. They are placed midway between the main poles and the interpole windings are in series with the armature. However, since armature reaction distorts the main field in a motor in the opposite direction, the polarity of the interpoles must differ from those of a generator. A north main pole precedes a north interpole as indicated in figure 109, the wiring diagram of a four-pole interpole motor.

MOTOR OUTPUT AND EFFICIENCY

Motors are rated for how big a load they can drive, or their POWER OUTPUT. The power output is the horsepower delivered by the motor at full load. Motors are rated for how economical they are by EFFICIENCY. Efficiency is the ratio of power output to power input, expressed in percent. The power input to a motor, as you just learned, is the sum of the power output and the losses. Therefore—

$$\text{Efficiency} = \frac{\text{Power Output}}{\text{Power Input}} = \frac{\text{Power Input} - \text{Losses}}{\text{Power Input}}$$

(Multiplying by 100 gives efficiency in percent)

You can use either above formula to solve problems, but remember to WATCH the UNITS. The INPUT to a motor IS ELECTRICAL POWER, MEASURED IN WATTS. OUTPUT IS MECHANICAL POWER, and ITS UNIT IS HORSEPOWER. In an equation you are really comparing two quantities, so both must be the same type of thing. Thus in either formula, you must keep all the terms in the same units—have everything in watts or everything in horsepower. The relation between the two is—

$$746 \text{ watts} = 1 \text{ horsepower}$$

Consider this example: The output of a motor is 5 horsepower (5 hp) and its efficiency is known to be 90%. What is the power input?

$$\text{Efficiency} = \frac{\text{Power Output}}{\text{Power Input}}$$

$$.90 = \frac{5}{\text{Power Input}}$$

$$.90 \times \text{Power Input} = 5$$

$$\text{Power Input} = \frac{5}{.90}$$

$$\text{Power input} = 5.55 \text{ horsepower}$$

Here we used the power output in horsepower, so this tells us that the power input is 5.55 horsepower. But the input is electrical power, usually measured in watts, so you want to know how much this 5.55 hp input is in watts. You know that—

$$1 \text{ horsepower} = 746 \text{ watts}$$

So—

$$5.55 \text{ hp} = 5.55\ (746) \text{ watts}$$

and—

$$\text{input} = 4150 \text{ watts.}$$

TYPES OF DIRECT CURRENT MOTORS

The connections of fields and armature in motors are the same as in generators. The only differences between motors and generators are mechanical. Thus a motor, like a

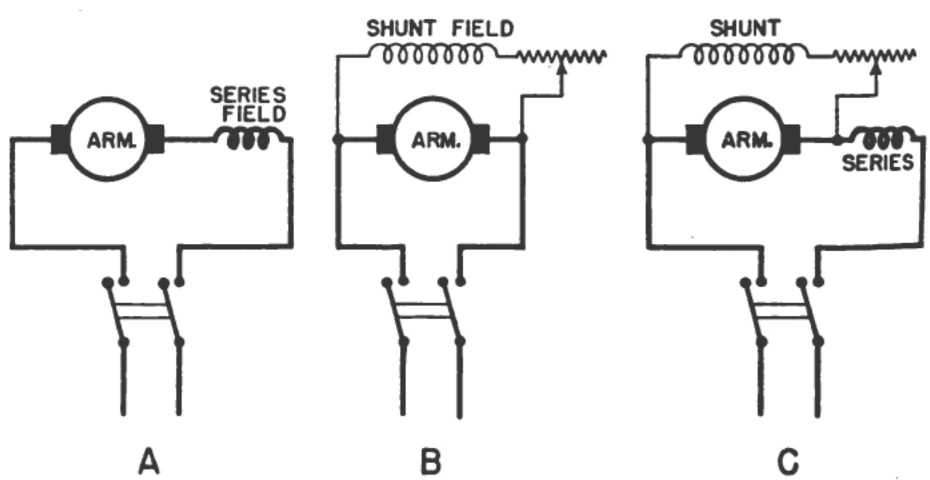


Figure 110.—Schematic diagrams for series, shunt, and compound motors.

generator, may be SERIES, SHUNT, or COMPOUND. The three types are diagrammed in figure 110. The COMPOUND motor

may be either CUMULATIVE or DIFFERENTIAL, depending on whether the series field aids or opposes the shunt field. The SHUNT fields may be SHORT or LONG shunt, as in compound generators. (See Ch. 7.) Generally the long shunt is preferred.

MOTOR CHARACTERISTIC

Just as explained in chapter 7 for a generator, you can tell the whole story about the operation of a motor in a simple graph called the MOTOR CHARACTERISTIC. Only in the case of a motor the important factors to be shown on the graph are the motor speed and its torque. Since torque is directly proportional to the armature current for most types of d-c motors, the graph may have armature current along one axis in place of motor torque. The characteristic curves for the three types of motors are shown in figure 111.

THE SERIES MOTOR

A series motor is diagrammed in figure 110A. This type has a field of large wire connected in series with the armature. Any additional load that is added to a series motor will cause more current to flow through the armature to produce the necessary torque. Since this increased current must go

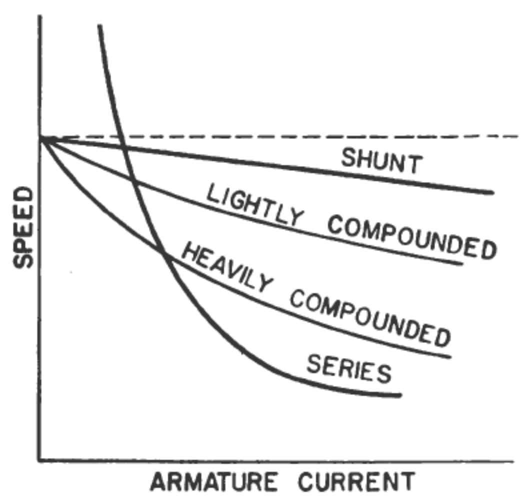


Figure 111.—Series, shunt and compound motor characteristics.

through the series field, there will be a greater field flux which in turn will produce a large counter-electromotive

force at low speed. The motor speed will therefore greatly decrease. Thus the characteristic of a SERIES motor, as shown in figure 111, is that SPEED CHANGES RAPIDLY WITH TORQUE, and when TORQUE IS HIGH, SPEED is LOW; or if torque is low, speed gets high. Therefore, NEVER START A SERIES MOTOR WITHOUT A LOAD OR REMOVE THE LOAD from it while the motor is running. FOR if a series motor is started without a load, the field current is small and the cemf would tend to equal the applied voltage, which means the MOTOR WILL GAIN SPEED UNTIL the speed gets up so high that the motor will be DAMAGED.

The characteristics of a series motor are excellent for starting heavy loads that are coupled to the motor at all times, because if the current in a series motor armature is doubled the torque will be about four times as great. The speed of a series motor can best be controlled by inserting resistance in series with the armature.

THE SHUNT MOTOR

A shunt motor diagram is illustrated in figure 110B. The shunt motor field is across the line or in parallel with the armature. The rheostat in series with the field winding is used for speed control.

In a shunt motor the field current stays the same, regardless of changes in armature current. Therefore in a shunt motor when the ARMATURE CURRENT IS DOUBLED, the TORQUE IS DOUBLED. Also the SPEED of a shunt motor CHANGES VERY LITTLE WITH change of LOAD, the SPEED INCREASING WHEN the LOAD DECREASES. These operating characteristics are all brought out by the shunt characteristic curve in figure 111. As you will note from this graph, the speed of a shunt motor with full load will be only about 10% less than with no load. Shunt motors are therefore used where the speed of the load must always remain practically constant. In an earlier paragraph on MOTOR SPEED you saw why the speed of a shunt motor changes very little with changes of load.

If the speed of a shunt motor is to be changed, this is done by changing the field resistance. The rheostat in series

with the field controls the current through the field coils. By inserting MORE RESISTANCE IN series with THE FIELD, less field current will flow, there will be less lines of force for the armature coils to cut, and the ARMATURE MUST RUN AT HIGHER SPEED to generate the required counter emf. As a result the armature speed increases. If the FIELD RESISTANCE IS DECREASED, more current flows through the field producing a greater flux, and the MOTOR SLOWS DOWN. In the preceding paragraph on MOTOR SPEED CONTROL BY CHANGING FIELD you saw how this works.

STABILIZED SHUNT MOTOR

Some motors have a small series field added to the shunt motor which field produces the characteristics of a shunt motor with a small effect of the series motor added. The small series field tends to add a small resistance to the armature circuit limiting the armature current to some degree.

COMPOUND MOTORS

Compound motors differ from the stabilized shunt types by having a more predominant series field. Like compound generators, compound motors can be divided into two classes, DIFFERENTIAL and CUMULATIVE depending on the connection of the series field in relation to the shunt field.

DIFFERENTIAL COMPOUND MOTORS

A diagram of the differential compound motor is shown in figure 112A. In this type the series field opposes the connected shunt field. Therefore this motor operates at prac-

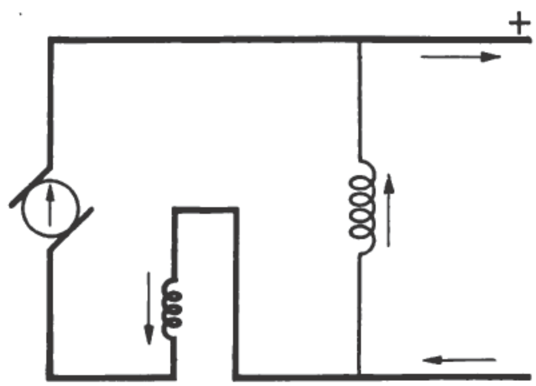


Figure 112A.—Differential compounded motor.

tically a constant speed. This is how it works: As the load increases the motor tends to slow down, and the armature current increases to provide more torque. The series field magnetism increases, weakening the shunt field magnetism, with the result that the speed is increased enough to overcome any decrease caused by the load.

CUMULATIVE COMPOUND MOTOR

The cumulative compound motor diagrammed in figure 112B is connected so its series and shunt fields aid each other.

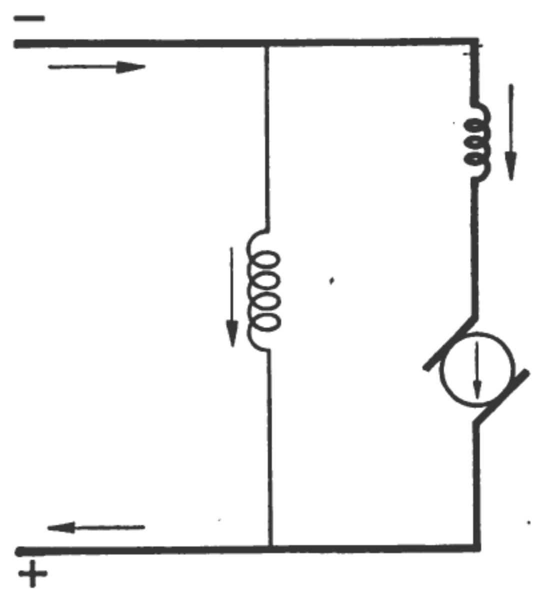


Figure 112B.—Cumulative compound motor.

While it is not a constant speed motor, its torque, owing to its series characteristics, is greater than with the differential type. Being a high-torque motor, it is especially useful in installations subject to sudden over-loads, both at starting and while running. Frequently motors of this type are merely series motors provided with sufficient shunt turns to prevent the motor from running away when operating at no load. Sometimes they are called SERIES-SHUNT wound motors.

OVER-, UNDER-, AND FLAT-COMPOUNDED MOTORS

As in generators, the number of turns in the series field determines how much the series field flux aids or opposes

the shunt field flux. The speed and torque characteristics of the cumulatively compounded motor may approach those of the shunt or series motors depending upon the relative strength of the two fields. If a motor contains a light series winding, it will have better torque than a shunt motor, but will retain the shunt motor's good speed regulation. If the motor has a light shunt winding and a heavy series winding, it will have the characteristics of a series motor, but will not run at a dangerous speed with light loads.

Compound motors are used for driving machines that demand a fairly constant speed and are subject to irregular loads or sudden applications of heavy loads. They are used also where it is desired to partially protect the motor by causing it to decrease speed under heavy loads.

REVERSING DIRECTION OF ROTATION OF MOTORS

You can REVERSE the direction of MOTOR ROTATION BY REVERSING either the FIELD OR ARMATURE CURRENT, but not both. Figure 113, in part *A*, shows the conditions necessary for clockwise rotation. In part *B*, the armature current is reversed but the fields remain as before, and you get counter-clockwise rotation. In *C*, only the field is reversed and you

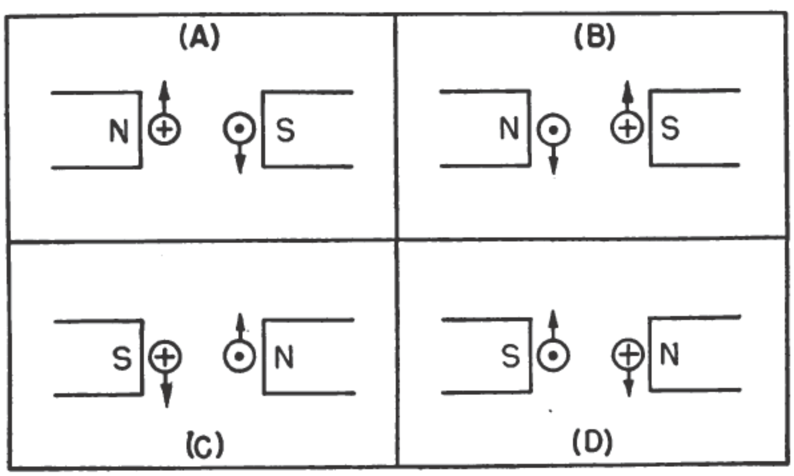


Figure 113.—How to reverse a motor.

also get counter-clockwise rotation. In *D*, both the fields and armature are reversed and you do not change the direction of rotation.

Parts A and B of figure 114 show the simple connections for reversing a series motor by changing the direction of current through the armature. In part A the switch S is on contacts 1 and 2, and the direction of current through the armature is as shown. Now if the switch S is put on contacts 2 and 3 as in part B the current through the armature is reversed.

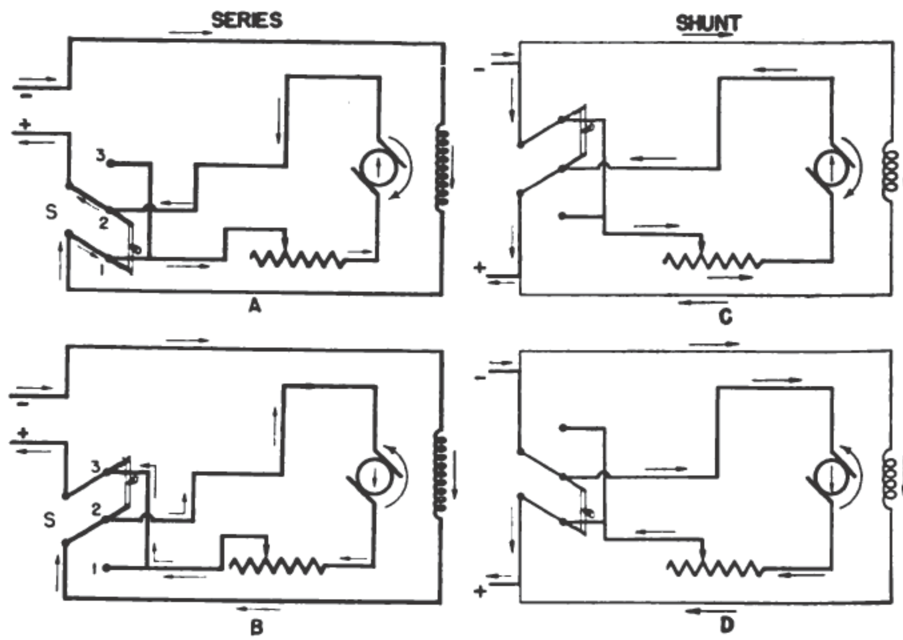


Figure 114.—Reversing a d-c motor.

Figure 114, parts C and D show the simple connections for reversing the direction of rotation of the shunt motor.

The connections for a compound motor would be the same as for a series motor, the series field being outside of the reversing switch as shown for the series motor in figure 114, parts A and B.

DIRECT CURRENT MOTOR TROUBLES

A direct current motor has its troubles just like any other piece of equipment. If you can recognize the symptoms of the ailment and quickly apply the cure, the effect of these ills will be relatively unimportant. The troubles of motors and generators are very similar and both are treated in chapter 10.

QUIZ

1. Complete the following statements:
   (a) If electrical energy flows from the line into a d-c generator (instead of from the generator into the line) the generator will operate as a ______.
   (b) A direct current generator has the same parts as a d-c ______.
2. What are the two principal differences in construction between direct current generators and motors?
3. Complete the following statements:
   (a) If a current-carrying conductor is placed in a magnetic field, the field exerts a ______ on the conductor.
   (b) A current-carrying conductor placed in a magnetic field tends to move ______ the field.
   (c) Motor torque is the ______ of a motor to turn a mechanical load.
   (d) The torque of a motor can be increased by increasing the motor's:
      1. field ______.
      2. armature ______.
      3. armature conductor ______.
   (e) Motor torque can be expressed by the formula
   Motor Torque=
4. Complete the following statements:
   (a) The right hand rule for a motor says that if you place the right hand so that:
      1. the ______ enters the palm
      2. the extended fingers point in the direction of______
      3. the thumb, placed at right angles to the fingers, points in the direction of ______.
5. Complete the following statements:
   (a) The emf generated in a motor armature, due to armature conductors cutting the motor field, is called a ______ electromotive force.
   (b) The emf generated in a motor armature, due to armature conductors cutting the motor field, ______ the line voltage.

(c) Motor cemf is proportional to:

1. rotation ______.
2. field ______.

(d) The formula for motor counter electromotive force is

$$Ec=$$

(e) Voltage drop due to current flow through the armature resistance is given by the formula

$$Ea=$$

(f) The motor line voltage is the sum of the ______ and armature drop.

(g) The motor counter electromotive force automatically limits the armature ______.

6. Complete the following statements:

(a) When a motor is at rest, no *cemf* is generated, so the armature current is limited by starting ______.

(b) As motor *cemf* builds up with increasing speed, the starting ______ are cut out.

(c) The device which switches resistances into or out of the motor circuit is called a motor ______ or ______.

(d) An electric motor automatically changes its torque as the ______ changes.

(e) An electric motor automatically adjusts itself so that when the load gets heavier the speed gets ______.

(f) A d-c motor tends to run at such a speed that the sum of counterelectromotive force and armature drop equals ______.

7. Complete the following statements:

(a) The three ways to change motor speed are:

1. Change motor ______.
2. Change field ______.
3. Change line ______.

(b) The equation for finding motor speed is

$$S= \_\_\_\_\_\_.$$

8. A motor operates on a line voltage of 115 volts, has a design constant (k) of 0.1 (10^{-6}), a field flux of 1,000,000 lines. What is its speed at full load, when its armature drop is 10 volts?

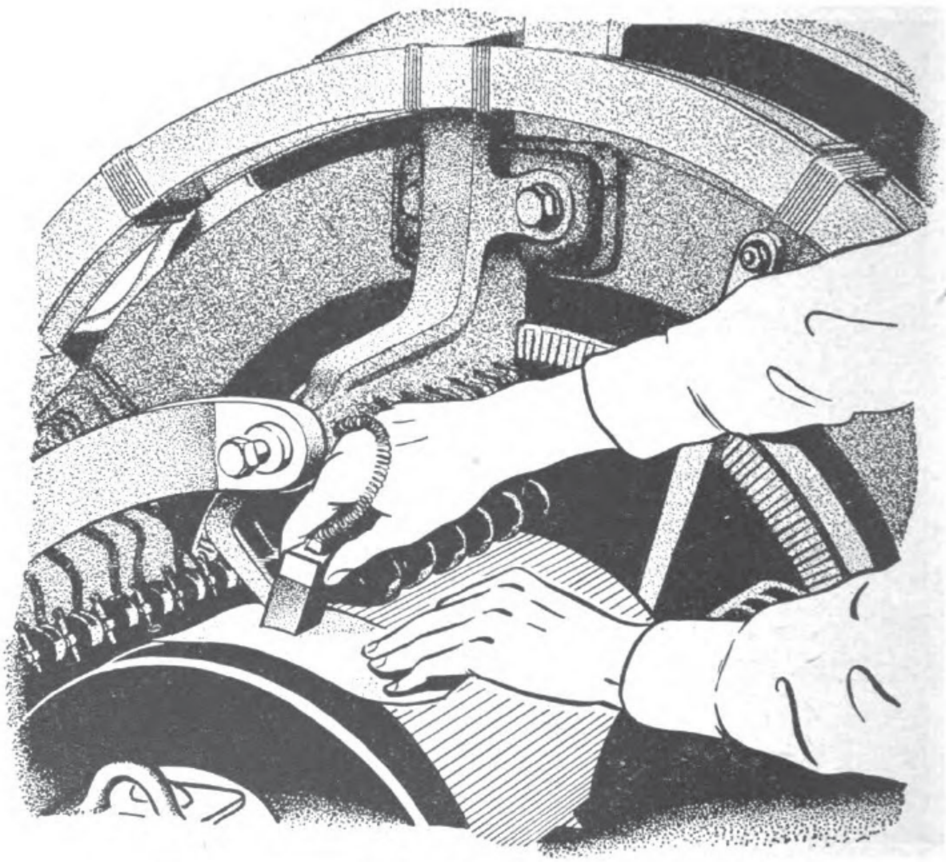
9. Complete the following statements:
   (a) Electrical power input to a motor is given by the formula Power input=line voltage × ------.
   (b) Mechanical power output of a motor is given by the formula Power=Torque × ------.
   (c) The motor power output given by the above formula is expressed in ------ per minute.
   (d) Motor output in horsepower is given by the formula

$$\text{Power} = \frac{\text{Torque} \times \text{------}}{33{,}000}$$

   (e) Efficiency of a motor is given by the equation

$$\text{Efficiency} = \frac{\text{Power------}}{\text{Power}}$$

   (f) One horsepower is equivalent to ------ watts.
10. A 230-volt motor draws a current of 10 amperes. If the motor efficiency is 80 percent, find:
   (a) motor input in watts
   (b) motor input in horsepower
   (c) motor output in horsepower
11. Name the three types of d-c motors.
12. Name the two types of d-c compound motors.
13. Complete the following statements:
   (a) The graph showing change of motor speed or motor torque is called a motor ------.
   (b) In a series motor, speed ------ as load decreases.
   (c) The danger in running a series motor with little or no load is that its speed becomes ------.
   (d) In a shunt motor the field is connected ------ the armature.
   (e) A shunt motor is essentially a ------ speed motor.
   (f) To reverse the direction of rotation of a d-c motor you reverse either its ------ or the ------.



CHAPTER 10

MAINTENANCE OF DIRECT-CURRENT MOTORS AND GENERATORS

ELECTRICAL MAINTENANCE—NOTHING TO FEAR

To the striker for EM3 with little experience afloat electrical maintenance raises up visions of mysterious, brain-puzzling excursions into electrical circuits requiring the use of any number of impressive looking instruments, and making necessary the picking up of a vast technical background.

This idea can be debunked considerably by pointing out that most of our equipments are good standard American gear of sturdy construction and good design. They have been manufactured to meet very stiff specifications and with proper care will give trouble-free operation over a considerable period of time.

Actually, successful maintenance afloat is at least 80% good housekeeping with certain differences between conditions ashore and afloat kept in mind. This being true, the more or less non-technical striker may lose much of his fear of inability to keep his equipment in good operating condition. While in the following he may feel that at some points undue emphasis is being placed on "spit and polish", he will learn by experience that most trouble may be directly traced to the lack of it.

SHIPBOARD ELECTRICAL MAINTENANCE

There are any number of electrical installations ashore where the equipment is installed and proceeds to operate for years with no major breakdown. The same equipment installed on a seagoing ship may very promptly suffer a major breakdown unless given the proper seagoing care.

The answer to this lies in the fact that a ship contains very powerful engines that operate for long periods of time and while in operation subject everything aboard that ship to continuous vibration. While the electrician's mate may not be physically aware of this never-ending source of trouble he must keep in mind that every one of the thousand or more separate and distinct connections in his equipment, down to the last soldered joint, terminal post, lug and hexagon nut is continuously subjected to a loosening force. Special care for seagoing equipment is also needed because airborne dust in a ship is largely metallic while the air itself aboard ship may be moisture laden. Metal dust or moisture therefore gradually accumulates on the equipment, forming voltage breakdown paths. These facts coupled with others to be presented will give the striker for EM3 an insight into successful maintenance and bolster his confidence by removing many of the "bogies" that seem to have attached themselves to electrical maintenance afloat.

BEARINGS—THE HEART OF ROTATING ELECTRICAL MACHINES

It may truthfully be said that the life of a rotating machine is to a great extent dependent upon the life of its bearings.

These bearings in turn depend upon the lubrication afforded them, and while pages may be written on the subject of lubrication, the electrician's mate need only develop the proper insight into its purpose to satisfactorily care for his machines. Generally speaking there are two types of bearings—FRICTION and ANTI-FRICTION. The FRICTION bearing is a soft metal sleeve in which the shaft revolves. The shaft rides on a film of oil produced by oil grooves in the bearing sleeve.

If there is no oil in this bearing, you can see what happens if you visualize a shaft resting in a bearing sleeve support and then imagine yourself looking at both shaft and support surfaces through a very powerful magnifying glass (fig. 115A).

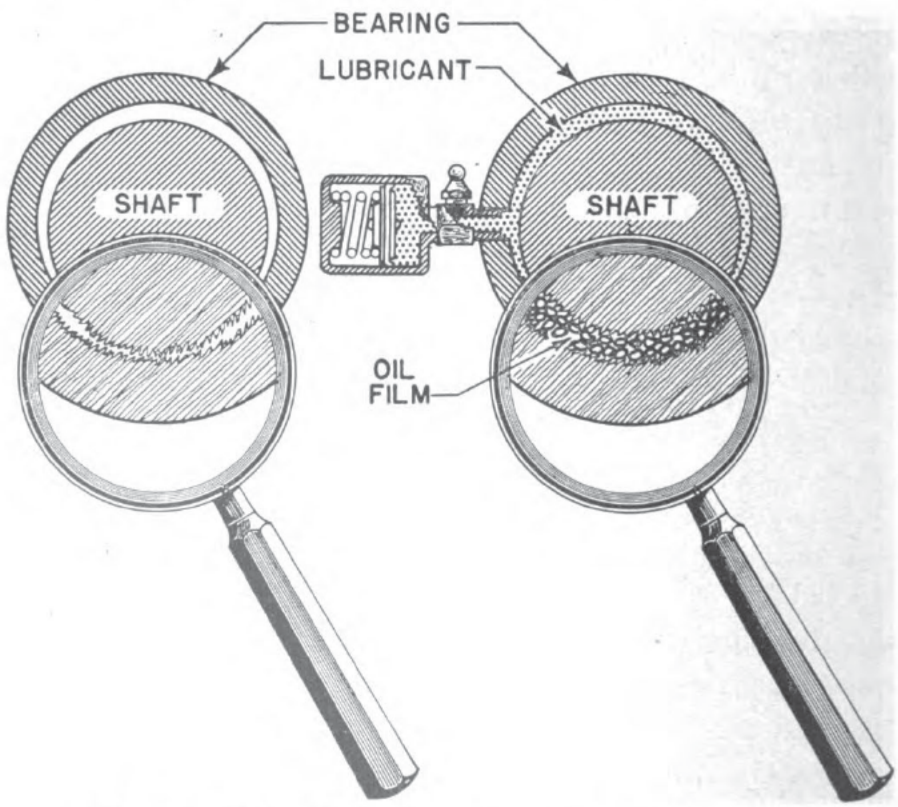


Figure 115A.—Solid and fluid friction in bearings.

Such a view would reveal innumerable tiny projections from each surface and if the shaft is rotated, these projections would interlock, chipping and breaking off to form new minute projections which continue the process. Such action is known as SOLID FRICTION and if continued will produce sufficient wear to ruin both surfaces.

To one who has no background in chemistry it will seem a little hard to understand how a layer of oil may support a shaft clear of the supporting surface. Nevertheless, this is the case. If you have a layer of oil between the shaft and its sleeve support, then upon rotation, the minute projections pass through oil; no interlocking occurs, and we then have merely what is known as FLUID FRICTION. The type of shaft support described is known as a SLEEVE BEARING and it is readily identified by the presence of oil chambers. There will be no wear on the bearings as long as sufficient oil is present and that oil has not lost its body or strength to support the shaft. This of course assumes that no foreign particles are present and free distribution of the oil exists.

Where a ball or roller bearing is used the rolling action eliminates the possibility of solid friction and for this reason they are known as ANTI-FRICTION bearings. The balls (or rollers) are enclosed in runways known as RACES and the spacing between the roller member and the races is very critical. The introduction of foreign particles into this area will cause wear and tear of the ball and race and will eventually render the bearing useless. Ball and roller bearings are packed in grease. The purpose of this grease is to lubricate and to exclude foreign materials from the bearings. Rotation and the heat generated causes small losses of the

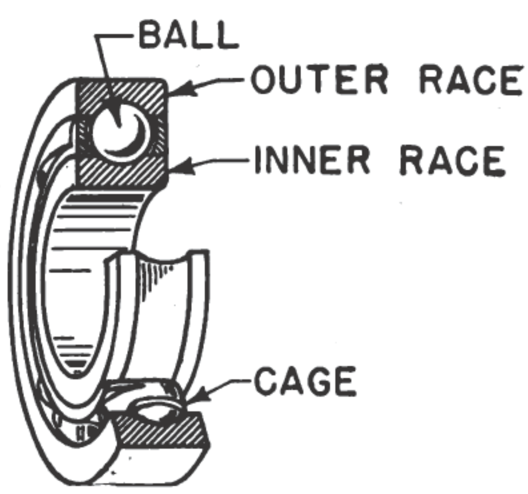


Figure 115B.—Ball bearing.

grease which must be replaced. Practically all anti-friction bearings will be accompanied by a tube and screw cup containing renewal grease. Normally one half turn a month is sufficient to care for the bearing.

On smaller machines you will sometimes find bearings without facilities for lubrication. A patented bearing generally known as the OILITE BEARING is used in many of these and the bearing itself contains a high percentage of oil which is forced out of the pores of the metal when the bearing becomes heated by rotation. This is somewhat similar to underwater bearings made from a wood called LIGNUM VITAE, which oozes out oil when wet.

LUBRICANTS

Some knowledge of oil and grease is required by the electrician's mate so that he may have proper respect for the use of correct lubricants for the job at hand.

Lubricants are designated as GREASE or OIL. There are two main sources of oil—VEGETABLE and MINERAL. The vegetable oil possesses the advantage of being much more "oily" than is mineral oil but its acid content is high. Mineral oils are satisfactory for most lubricating jobs but often a certain amount of vegetable oil is mixed with it to meet the requirements of various jobs. Any number of considerations enter into the composition of oil, some of which are: to prevent gumminess; to permit high, low, or varied temperature operations; to maintain a given viscosity over long period of time; and to have low inflammable ratings. From this the electrician's mate may understand reasons for so many types and specifications of oil to meet various jobs, and will realize THE IMPORTANCE OF USING THE OIL INDICATED AS CORRECT FOR THE JOB.

GREASE may be broadly described as oil mixed with soap. As with oils, many factors enter into the composition of a grease—preventing corrosion, permitting operation in high and low temperature, etc., and increase the number of different types and specifications. The U. S. Navy, through far reaching and exhaustive studies of lubrication, has become more or less the authority on lubrication, and its

specifications for oils and greases are accepted as the standard even by many civilian activities.

Above all the electrician's mate must guard against regarding any common lubricant that happens to be on hand as satisfactory for all jobs encountered. Were this the case much economy could be effected by simply loading aboard a barrel of lubricating oil and letting it go at that. The wealth of instruction book material devoted to lubrication and the care that has been taken to include special lubricants in spare parts boxes more than prove to the electrician's mate the importance of USING ONLY THE RIGHT LUBRICANT FOR THE JOB in the maintenance of rotating electrical machinery.

TO KEEP IT WORKING—KEEP IT CLEAN AND LUBRICATED

In the upkeep of rotating machines the two main requirements are that of proper lubrication and cleanliness. Quite often the removal of end plates from a machine reveals the presence of excess oil and grease on the brush mountings and windings. This is the result of OVERLUBRICATION which is TO BE CAREFULLY AVOIDED. Regulations forbid the use of power or lever operated grease guns on Navy equipment for this reason.

Although the machine may appear to be well protected with dustplates and other devices, an internal examination will reveal a fan assembly mounted on the shaft for the purpose of drawing in a draft of air to cool the windings. This means that dirt can penetrate the enclosure and collect within. Dirt is a heat insulator and contributes to obstructing the cooling flow of air, therefore accumulations of it must be removed periodically.

Cleaning of the commutator shall be carried out in accordance with the instructions below for COMMUTATOR MAINTENANCE, keeping in mind that it may be done ONLY WHEN THE MACHINE IS TURNED OVER BY HAND, NEVER WITH THE POWER APPLIED.

CARE OF COMMUTATORS

Next to bearings, commutators and brushes are the chief source of trouble in d-c motors and generators. Therefore it

is important to make frequent inspections of running equipment to eliminate any sparking that may be noticed at the brushes. If sparking is allowed to continue, the degree of sparking becomes progressively greater as the commutators become more and more pitted from burning.

A commutator in proper condition shows a DARK CHOCOLATE COLOR. This color is due to the action of the brushes in riding on the rotating commutator. It is not necessary that a commutator always presents a bright, shiny appearance. However, any roughness should be smoothed immediately, otherwise the conditions will grow progressively worse. Slight roughness may be removed by the use of fine sandpaper held in a block shaped to fit the curvature of the commutator. If the commutator is very rough or grooved, smooth it by using a commutator stone, or by taking light cuts while the armature is in a lathe. This work should be done ONLY BY EXPERIENCED PERSONNEL. NEVER USE EMERY CLOTH on a commutator as the particles of emery are very hard and might become imbedded in the riding surface of the brush and cut grooves in the commutator.

Each time a generator has been running, or after the commutator has been smoothed, the commutator should be "blown out" with DRY compressed air to eliminate all foreign particles. A commutator may be cleaned of dirt by holding a piece of tightly rolled light canvas on its surface while it is rotating.

If mica insulation between commutator segments is cut below the top surface of the segments the commutator is said to be UNDERCUT. The undercut usually is of a depth between $\frac{1}{32}$ inch and $\frac{1}{16}$ inch. Most modern generators have undercut commutators, and use brushes that are not as hard as those used with commutators that are not undercut. The brushes used with older machines without undercut commutators had to be hard enough to wear down the copper bars and mica uniformly. The older type brushes were not of as high a grade of carbon and therefore were not as well adapted to commutation. Most brushes now used are made of a high grade carbon, which has correct resistance and is self-lubricating. Each brush should be free to slide up and down

in its holder, so it may follow all irregularities on the surface of the commutator bars. The brushes are made to bear upon the commutator with a spring adjusted to a pressure of 1½ to 2 pounds per square inch of brush surface riding on the commutator. Too LOW A PRESSURE CAUSES unnecessary SPARKING and TOO GREAT a PRESSURE will CAUSE EXCESSIVE BRUSH WEAR.

Keeping brush pressure correctly adjusted is especially important because arcing at the brushes will pit the commutator. This pitting, in turn, will prevent the brush from making good contact with the commutator, thus causing more arcing.

CAUSES OF SPARKING

Listed below are some of the more common causes of sparking at the brushes with a remedy for each. For a complete list of commutator troubles and their remedies see the paragraph below on trouble shooting.

Brush ROCKER RING AT WRONG LOCATION. Move the ring to correspond to the bench mark on the frame.

BRUSHES WRONGLY SPACED around commutator. If brushes are not equally spaced around the commutator look for a bent brush holder or rocker ring and eliminate the trouble.

POOR BRUSH CONTACT. Caused by insufficient brush pressure, in most cases, or by a high spot on the brush surface riding on the bars. Remedy by adjusting spring tension to proper amount, or sand brushes to a correct curvature, whichever is needed.

COMMUTATOR DIRTY OR ROUGH. Remove dirt with a roll of light canvas. Use fine sandpaper to remove slight roughness.

COPPER embedded IN BRUSH SURFACE. Remove brush and scrape copper from surface. Then re-sand brush to correct curvature.

COMMUTATOR BARS HIGH, LOW, OR LOOSE. Use a mallet to tap the high bar or loose bar back into place, and then tighten nuts on outside end of commutator. Then take a light cut on bars to smooth any high points. For low

bar, place armature in a lathe and take light cuts until the surface of all bars is of uniform height. *Caution:* To be done by experienced personnel ONLY.

SHORT-CIRCUITED ARMATURE COIL OR COMMUTATOR BARS. Find and remove the short circuit. See trouble shooting.

OVERLOADED MACHINE. Reduce the load on the generator or motor.

GROUND TESTS

Grounds on the ship's electrical equipment are usually caused by poor or broken insulation, which allows the current in the conductor to leak to the skin of the ship. This leakage further breaks down the insulation, so the grounding action, once started, becomes cumulative. Since this action is cumulative, all circuits must be given a ground test once each day. Use a megger to test for grounds. Instructions for using the megger usually are included with each instrument. If the reading on any circuit is lower than the permissible minimum, the source of trouble must be located and eliminated immediately.

Moisture and excessive heat are the greatest causes of the start of insulation breakdown. Excessive heat is due mainly to overloading. Moisture in generators may come from water thrown directly on the machine or by condensation from the atmosphere. Moisture in an armature may be removed by drying with heaters or lamp banks capable of producing a temperature of approximately 150° F. in the windings. A blower delivering hot, dry air may be used also. If the above methods fail, remove the armature from the machine and dry it in a bake oven. *CAUTION:* Oven drying to be done ONLY under immediate and constant supervision of the Chief Electrician's Mate.

Field coils may be dried by passing a small current, about ¼ rated value, through them until heat is present. If no sign of trouble develops, the current may be increased to the rated field current value and left on until the insulation resistance is of a satisfactory value.

Oil or grease may be removed from the generator windings by wiping with cheese cloth dipped in clear carbon tetra-

chloride. *CAUTION:* Do not allow fumes from carbon tetra-chloride to overcome you. THIS IS especially DANGEROUS IN CLOSED, CONFINED SPACES.

OTHER TESTS AND RECORDS

WEEKLY. Run all idle generators for at least 30 minutes and enter the fact in the log.

QUARTERLY. Make a thorough insulation test on all lighting, power, internal communication, and fire control circuits and enter readings on sheet or log provided for the purpose. Make insulation tests on the windings of all spare armatures and turn the armatures through three-fourths of a revolution.

ANNUALLY. Secure all power from main generators to switchboards. Examine thoroughly all circuits for damaged insulation, loose connections, and the like. Also thoroughly inspect all switchboards from behind for loose connections. Remedy all deficiencies and then thoroughly clean with a dry air blast. Enter the above operation in the log. This work is usually accomplished during the annual Navy Yard overhaul period.

SAFETY

All electrical equipment instruction books will commence with a warning as to the danger of loss of life in the operation and maintenance of high voltage equipment. The Electrician's Mate will encounter many similar warnings throughout his career and the constancy of these reminders are intended to keep him continuously alert to an ever present danger. Men have been killed by only a few volts, as in the case of the man aloft receiving a static discharge from an antenna which caused involuntary relaxation of his handgrip and the resultant fall to the deck below. Many safety devices are incorporated into the design of electrical equipment, the most familiar of which is the safety interlock. As a general rule all access doors that may be opened without the use of tools are guarded by safety interlocks. Although this might be regarded as a very good contribution to safety, statistics prove that reliance should never be

placed on them. There is ONE GOOD RULE to follow BEFORE ENTERING ELECTRICAL CABINETS or working on electrical equipment and that is, OPEN THE LINE SWITCH even though you may need to trace all the way down to the engine room distribution board to find it. To INSURE the SWITCH REMAINING OPEN a SIGN SHOULD BE PLACED ON IT to caution that men are at work on the equipment. Even though power may be removed, some components such as the large capacitors in the power units of electronic gear may retain deadly charges and should be shorted across with an insulated shorting bar before commencing work in their vicinity. Further safety precautions are given in chapter 17.

TROUBLE SHOOTING

Electric power is the life-blood of your ship. Should your ship's electricity supply give out, the ship is thrown into total darkness; its radio voice could not speak, its radar eyes could not see, its sonar ears could not hear, its fire control brain could not think. Furthermore, electrical drives are the muscle power of your ship. It is electrical drives that propel your ship, operates its steering gear, ventilate the holds and turrets, drive the ammunition hoists and aim the guns at the target. In short, when electrical equipment goes out of order it ties up much of the ship's machinery and paralyzes many of the ship's functions. Therefore as an Electrician's Mate you are a vital and valued man to have on board, but your value and importance depend mostly on how fast and how well you can shoot trouble on electrical gear and get it back into working order.

Trouble-shooting ability is a sort of "sixth sense" that you develop with experience. However, you can greatly shorten the time it takes to pick up this experience if you will study what others have learned in this field before you. The experience which many capable Electrician's Mates have gained in trouble shooting has therefore been summarized in the TROUBLE ANALYSIS AND CORRECTION CHART that you will find in the following pages. Studying this chart will not only give you the answers to many tough trouble-shooting problems; it will also develop that reasoning power which

enables you to "spot" the cause of electrical troubles and to think up ways to correct them.

The corrections indicated in this chart should be carried out according to the SERVICING INSTRUCTIONS given IN THE INSTRUCTION BOOK that you get FOR EACH UNIT OR EQUIPMENT. Anything in those instructions that you do not understand, do not hesitate to ask the Chief Electrician's Mate. In fact, BEFORE PERFORMING ANY of the TESTS OR REPAIR OPERATIONS indicated in the trouble analysis chart, be sure to GET DETAILED INSTRUCTIONS FROM YOUR EM CHIEF as to how he wants you to do it.

TROUBLE ANALYSIS AND CORRECTION CHART D-C MOTORS AND GENERATORS

FAULT	PROBABLE CAUSE	CORRECTION
SPARKING AT THE BRUSHES; MOTOR OR GENERATOR.	1. Brushes not set diametrically.	A. Brushes should be set properly, when machine is shut down, by counting bars or by measurement on the commutators. B. Can be done if necessary while running; move rocker until brush on one side sparks least, then adjust other brushes so they do not spark.
	2. Brushes not set at neutral points.	A. Move rocker back and forth slowly until sparking stops.
	3. Brushes not properly trimmed.	A. Brushes should be properly trimmed before starting. If there are two or more brushes one may be removed and retrimmed. B. Clean with alcohol or ether, then grind and reset. See causes 1, 4, 38.
	4. Brushes not in line.	A. Adjust each brush until its bearing surface is in line and square on commutator bar, bearing evenly the whole width. See cause 13A.

FAULT	PROBABLE CAUSE	CORRECTION
SPARKING AT THE BRUSHES; MOTOR OR GENERATOR.	5. Brushes not making good contact.	A. Clean commutator of oil and grit. See that brushes touch. B. Adjust tension screws and springs to secure light, firm contact. See Cause 38, correction *B*.
	6. Commutator only slightly rough; slightly worn, in grooves or ridges; or slightly out of round.	A. Grind commutator with fine sandpaper on curved block, and polish with crocus cloth. NEVER USE EMERY in any form.
	7. Commutator very rough; severly worn in grooves or ridges; far out or round.	A. If commutator is too bad to grind down, turn off true in a lathe or preferably in its own bearings, with a light tool and rest. Make only a light cut, running slowly. Note—armature should have $\frac{1}{16}$-inch to $\frac{1}{8}$-inch end motion when running, to wear commutator evenly and smoothly. See cause 31. MUST BE DONE BY EXPERIENCED PERSONNEL ONLY.
	8. Commutator has high bars.	A. Set "high bar" down carefully with mallet or block of wood then clamp tightly end nuts, or file, grind or turn true. A high bar may cause singing. See cause 38.
	9. Commutator has low bars.	A. Grind or turn commutator true to the surface of the low bars. Must be DONE BY EXPERIENCED PERSONNEL ONLY.
	10. Weak magnetic field.	A. Broken field coil circuit. Repair break if external; rewind coils if internal. B. Shorted field coil circuit. Repair if short is external; rewind if internal. C. Machine not properly wound, or poles without proper amount of iron. No remedy but to rebuild machine or replace with another.

FAULT	PROBABLE CAUSE	CORRECTION
SPARKING AT THE BRUSHES, GENERATOR ONLY.	11. Excessive current in generator armature due to:	
	A. Excessive load on generator.	A. Reduce number of lamps or motors in generator load.
	B. Grounded lead on line.	B. Test out line, locate short and repair.
	C. Dead short circuit on line.	C. Dead short will or should blow safety fuse. Shut down, locate fault and repair. Put in new fuse before starting again.
	D. Excessive generator voltage output.	D. First check to insure proper load current and correct prime mover speed. Then adjust field rheostat to produce correct generator voltage.
	E. Excessive current taken by constant current 1 line.	E. See that controller, etc., are suitable with ample resistance.
	F. Short-circuited coils in armature.	F. Same correction as in cause 13.
	G. Cross-connection in armature.	G. Cross connection may have same effect as short circuit. Treat as such. See cause 13. Test each coil completely for cross connection or ground.
SPARKING AT BRUSHES, MOTOR ONLY.	12. Too much current in motor armature due to:	
	A. Too big a load on motor.	A. Reduce load on motor to its rated capacity or less. See causes 3, 35, and 36.
	B. Too much friction in motor or motor load.	B. Check motor and motor load for too much friction or mechanical resistance anywhere.
	C. Short circuited coils in armature.	C. Same correction as in cause 13.
	D. Cross connected coils in armature.	D. Cross connections may have same effect as short circuit; treat as such. Test each coil for cross connection and ground. See cause 13.

FAULT	PROBABLE CAUSE	CORRECTION
	13. Short circuited armature coils, due to:	
	A. Surface leak across commutator bars.	A. Remove copper dust, solder, or other metallic contact between commutator bars.
	B. Internal leak across commutator bars.	B. See that clamping rings are perfectly free and insulated from commutator bars; see that no copper dust or carbonized oil cause electrical leak across commutator bars.
	C. Shorted coils.	C. Test for short-circuited coils and if such are found rewind armature to correct.
	D. Coils cross-connected through commutator.	D. See that brush holders are perfectly insulated and have no copper dust, carbon dust, oil or dirt to cause electrical leak.
SEVERE SPARKING AT THE BRUSHES; MOTORS OR GENERATORS.	E. Coils cross-connected through coil windings.	E. Cross connections may have the same effect as short-circuit; treat as such. See A–D above. Each coil should be tested completely for cross-connection and ground.
	14. Open armature coil due to:	
	A. Broken coil connection to commutator bar.	A. Shut down machine as soon as possible, and repair loose or broken connection to commutator bar.
	B. Break inside coil.	B. Shut down machine. If coil is broken inside, rewinding is the only sure remedy. May be temporarily repaired by connecting a "jumper" across open coil's two commutator bars. Open both ends of the broken coil.

FAULT	PROBABLE CAUSE	CORRECTION
SEVERE SPARKING AT THE BRUSHES; MOTORS OR GENERATORS.	14. Broken armature coils due to B. Break inside coil—Continued.	Check to insure against accidental short or incorrect cross connection during this step. See cause 13.
OVERHEATING OF ARMATURE; MOTOR OR GENERATOR.	15. Machine overloaded.	A. Too much current being drawn from generator, or too large load on motor. Reduce lamps, motors, etc. fed by generator. Reduce load on motor. See causes 11, 12, 13, 14..
	16. Short circuit in armature.	A. Generally due to dirt, etc. at commutator bars. See causes 11, 12, 13, 14.
	17. Broken circuit in armature.	A. Often caused by a loose or broken band. See cause 14.
	18. Cross connection in armature core.	A. Often caused by a loose coil rubbing against another coil or the armature core. See causes 12, 13.
	19. Eddy currents in armature core.	A. Indicated by iron of armature being hotter than coils after run. Faulty construction. Core should be made of finely laminated insulated sheets. No remedy but to rebuild.
	20. Moisture in coils.	A. Dry out by gentle heat. May be done by sending a small current through, or causing machine itself to generate a small current by running slowly.
	21. Friction.	A. Hot boxes or journals may affect armature. See causes 25 to 33.

FAULT	PROBABLE CAUSE	CORRECTION
OVERHEATING OF FIELD COILS; MOTOR OR GENERATOR.	22. Excessive field current in: A. Shunt motor or generator.	A. Decrease output voltage at terminals (generator only) by reducing speed, or increase field resistance by making the windings of finer wire, or putting resistance in series with fields.
	B. Series motor or generator.	B. Decrease current through fields by shunt across field; by removing some of field windings; or by rewinding field with finer wire.
	23. Eddy currents.	A. Pole pieces hotter than coils after a short run, due to faulty construction or fluctuating current. If latter, regulate and steady current.
	24. Moisture in field coils.	A. Coils show less than normal resistance, may cause short circuit or body contact to iron of dynamo. Dry out as directed in cause 20.
OVERHEATING OF BEARINGS; MOTOR OR GENERATOR.	25. Not sufficient or poor oil.	A. Remove load but do not stop machine or hot bearing will freeze in journal. Drain out dirt from bearing well but keep fresh, clean oil flowing until bearing temperature is normal. Keep oil off commutator, brushes and armature. If journal freezes on shaft, machine must be dismantled, shaft polished, and new bearings fitted.
	26. Dirt or grit in bearings.	A. Wash out grit with oil while running, then clean up and put in order. Be careful about flooding commutator and brush holder. B. Remove caps and clean and polish journals and bearings, then replace. See that all parts are free and lubricate well.

FAULT	PROBABLE CAUSE	CORRECTION
	26. Dirt or grit in bearings—Continued	C. For dirt in grease-filled ball or roller bearings, remove housing and pull bearing, wash with Diesel oil until free from grit. If bearing surfaces are visibly damaged, replace with new bearing. Reassemble and fill with clean grease.
	27. Rough journals or bearings.	A. Smooth and polish in a lathe, removing all burrs, scratches, tool marks, etc., and rebabbitt old bosses and fit new ones.
	28. Bearings journals too tight.	A. Slacken cap bolts, put in liners and retighten till run is over; then scrape, ream, etc., as may be needed. Replacement of shaft or box with new one may be necessary.
OVERHEATING OF BEARINGS; MOTOR OR GENERATOR.	29. Bent shaft.	A. Bend or turn shaft true in lathe or grinder. Put in liners, scrape, ream, etc., as may be needed. Replacement of shaft or box with new one may be needed.
	30. Bearings out of line.	A. Loosen bearing bolts; line up and block, until armature is in center of pole pieces; ream out dowel and bolt holes and secure in new position.
	31. End pressure of pulley hub or shaft collars.	A. See that foundation is level and armature has free end motion. B. If there is no end motion, file or turn ends of boxes or shoulders on shaft to provide end motion. C. Then line up shaft and belt, so that there is no end thrust on shaft, and the armature plays freely endways when running.

FAULT	PROBABLE CAUSE	CORRECTION
OVERHEATING OF BEARINGS; MOTOR OR GENERATOR.	32. Belt too tight.	A. Reduce load so that belt may be loosened and yet not slip. Avoid vertical belts if possible. B. Choose larger pulleys, wider and longer belts with slack side on top. Vibrating and flapping belts cause winking lamps.
	33. Armature out of center relative to pole pieces.	A. Bearings may be worn out and need replacing, throwing armature out of center. See cause 36. B. Center armature in polar space, and adjust bearing to suit. See cause 30. C. Spring pole away from armature; this may be difficult or impossible in large machines.
NOISES; MOTORS OR GENERATORS.	34. Armature or pulley out of balance.	A. Faulty construction; armature and pulley should have been balanced when made. May be helped by balancing on knife edges now.
	35. Armature rubs or strikes pole pieces.	A. Bend or press down any projecting wires, and secure with tie bands. B. File out pole pieces where armature strikes. See causes 30, 33.
	36. Collars or shoulders on shaft strike or rub box.	A. Bearings may be loose or worn out. Perhaps new bearings are needed. See causes 30, 31.
	37. Loose bolt connection or screws.	A. See that all bolts and screws are tight, and examine daily to keep them so.
	38. Brushes sing or hiss.	A. Smooth commutator with a canvas roll or sandpaper very gently with machine running. Use 4/0 paper that has been rubbed against itself and smoothed off.

FAULT	PROBABLE CAUSE	CORRECTION
NOISES; MOTORS OR GENERATORS.	38. Brushes sing or hiss—Continued	B. Move brushes in and out of holder to get a firm, smooth, gentle pressure, free from hum or buzz. See causes 3, 6, 7, 8, 9, 31.
	39. Flapping of belt.	A. Use an endless belt if possible; if a laced belt must be used, have square ends neatly laced.
	40. Slipping of belt.	A. Tighten belt or reduce load. See cause 32.
	41. Humming of armature lugs or teeth.	A. Slope end of pole piece so that armature does not pass edges all at once. B. Decrease magnetism of field, or increase magnetic capacity of tooth.
GENERATOR SPEED TOO HIGH.	42. Engine fails to regulate with varying load.	A. Ask Engineman to check governor regulation from no-load to full-load.
MOTOR SPEED TOO HIGH.	43. Series motor; draws too much current, runs away.	A. Series motor on constant current line: (1) Put in a shunt and regulate to proper field current; or (2) use regulator or governor to control magnetism of field for varying load. B. Series motor on constant potential line: (1) Insert resistance and reduce current; or (2) use a proper regulator or controlling switch; or (3) change to automatic speed-regulating motor.
	44. Shunt motor; speed too high because: A. Field rheostat not properly set.	A. Adjust field rheostat to control motor.
	B. Motor power supply not correct.	B. Use current of proper voltage and no other, with proper rheostat.
	C. Motor not properly proportioned.	C. Get a motor better designed for the work.

FAULT	PROBABLE CAUSE	CORRECTION
GENERATOR SPEED TOO LOW.	45. Engine fails to regulate with varying load.	A. Ask Engineman to adjust governor of engine to regulate properly, from no-load to full-load.
	46. Generator overloaded.	A. Disconnect non-vital heavy power circuits, to reduce load. See cause 11.
MOTOR SPEED TOO LOW.	47. Short circuit in armature.	A. Due to short-circuited armature coils. Same causes and corrections in cause 13.
	48. Rubbing armature.	A. Same difficulties and corrections as in cause 35.
	49. Friction.	A. See difficulties and corrections in causes 25, 26, 27, 28, 29, 30, 31, 32, 33.
	50. Weak magnetic fields.	A. Same difficulties and corrections as in cause 10.
MOTOR STALLS OR HAS EXTREMELY LOW SPEED.	51. Extreme overload.	A. Difficulties and corrections same as in cause 12.
	52. Excessive friction.	A. Difficulties and corrections same as in causes 25, 33, 35. NOTE: Stalled or nearly stalled motor may blow fuse or burn out armature. Immediately open supply switch, find and repair trouble. Keep switch open and motor rheostat at off position until sure everything is right.

FAULT	PROBABLE CAUSE	CORRECTION
MOTOR FAILS TO RUN.	53. Motor circuit open due to:	
	A. Melted fuse or open switch.	A. Find and repair trouble after opening switch, then put in fuse. See cause 11C.
	B. Broken wire or connection.	B. Open switch, find and repair trouble. See cause 14.
	C. Brushes not in contact.	C. Open switch and adjust. See cause 5.
	D. Power supply fails or is shut off at generating station.	D. Open switch and return starting box lever to off position, wait for current.
	54. Short circuited motor field.	A. Test to locate short if possible. Examine insulation of binding posts and brush holders.
	55. Short circuited armature.	A. Poor insulation, dirt, oil and copper or carbon dust often result in a short circuit. Correct as indicated in cause 13.
	56. Short circuited motor switch.	A. Shut off power ahead of switch. Test with ohmmeter to locate short, and repair. See chapter on controllers.
MOTOR RUNS BACKWARDS.	57. Wrong connections.	A. Disconnect load from motor. Connect up motor correctly per diagram; if no diagram is at hand, reverse connections to armature (brushes) or to field until direction of rotation is correct.

FAULT	PROBABLE CAUSE	CORRECTION
GENERATOR OUTPUT OF REVERSED POLARITY.	58. Reversed field flux due to:	
	A. Reversed residual magnetism, produced by reverse current surge through field coils.	A. Use current from another machine or a battery through field in proper direction to correct fault. Test field polarity with a compass.
	B. Reversed field connections.	B. If connections or winding are not known, try one way and test; if not correct, reverse connections, try again and test. If connections are known, connect up as per diagram for desired rotation; see that connections to shunt and series coils are properly made. See cause 57.
	C. Reversed residual field produced by nearness of another dynamo.	C. Shift brushes until they operate better. See causes 1, 2, also 58A.
	D. Reversed residual field produced by brushes not being in right position.	D. See causes 1, 2, 3.
GENERATOR FAILS TO BUILD UP (PRODUCES NO OUTPUT).	59. Residual magnetism too weak.	A. Same cause and correction as 58A.
	60. Short circuit in generator.	A. Same causes and corrections as in cause 13.
	61. External circuit connected to generator.	A. A short or low resistance load in the external circuit may prevent building up shunt or compound machines. Always start a generator with line circuit disconnected.
	62. Field coils opposed to each other.	A. Reverse connections of one of field coils and test. Find polarity with compass; if necessary try corrections 58 A, C, D. If necessary reverse connections and recharge in opposite direction.

FAULT	PROBABLE CAUSE	CORRECTION
GENERATOR FAILS TO BUILD UP (PRODUCES NO OUTPUT).	63. Broken circuit due to:	
	A. Broken wire in generator.	A. Search out and repair. See cause 14.
	B. Faulty connections in generator.	B. Search out and repair. See cause 13.
	C. Brushes not contacting commutator.	C. Search out and repair. See cause 5.
	D. Fuses melted or broken.	D. Search out and repair. See cause 53A.
	E. Switch open.	E. Search out and repair. See cause 53D.
	F. External circuit	F. Search out and repair with dynamo switch open until repairs are completed.
	64. Too great load on dynamo.	A. Reduce load; after proper voltage is obtained close load switches in succession slowly, and regulate voltage. See cause 11.
	65. Too great resistance in generator field rheostat.	A. Bring up to voltage gradually with rheostat, and watch pilot lamp; regulate carefully.

QUIZ

1. Complete the following statements:
   (a) The chief causes of trouble in shipboard electrical installations are:
      1. Continuous ______ from the engines.
      2. Airborne dust aboard ship is ______.
      3. Air aboard ship is loaded with ______.
   (b) In a friction type bearing the shaft rides on an oil ______ in a sleeve support.
   (c) In an anti-friction bearing the shaft rides on balls or rollers enclosed in ______.
   (d) The primary purpose of the lubricant in anti-friction bearings is to protect against ______.
   (e) A sleeve bearing in which the lubricant comes out of pores in the metal is called an ______ bearing.

2. Complete the following statements:
   (a) Grease is composed of oil mixed with ------.
   (b) The two main sources of oil are mineral and ------.
   (c) The most important consideration in lubrication is to use the ------ lubrication for a particular job.
   (d) Oil and grease on brushes and windings results commonly from ------ lubrication.
   (e) Air-cooled electrical equipment accumulates ------ which must be removed periodically.
3. Complete the following statements:
   (a) Before doing any servicing on commutators be sure to ------ power.
   (b) When a commutator is in proper condition it shows a ------ color.
   (c) A slightly rough commutator should be smoothed by ------ held in a commutator block.
   (d) A very rough commutator should be smoothed by using a commutator ------.
   (e) Emery should not be used in smoothing a commutator because emery particles become embedded in the brush face and ------ the commutator.
   (f) After a commutator has been smoothed it should be ------ to remove all foreign particles.
   (g) Each brush should slide freely ------ and ------ in its holder.
   (h) Pressure of brushes bearing on commutators should be adjusted to ------ pounds per square inch.
   (i) Too low a brush pressure causes ------.
   (j) Too high a brush pressure causes ------.
4. Complete the following statements:
   (a) The common causes of excessive sparking at commutators are:
      1. Brush rocker ring (yoke) at wrong ------.
      2. Brushes wrongly ------ around commutator.
      3. Brush contact pressure ------.
      4. Commutator surface ------.
      5. Brush contact surface contains embedded ------.
      6. Commutator ------ high, low or loose.
      7. Armature coils or commutator bars ------.

8. Generator or motor load ------.

5. Complete the following statements:
   (a) Grounding due to insulation breakdown, once started, becomes ------.
   (b) Testing for insulation breakdown should be made with a ------.
   (c) Principal causes of insulation breakdown are moisture and excessive ------.
   (d) Armatures should be dried out by heating with heaters or air blast to not over ------ degrees Fahrenheit.
   (e) Field coils are dried by passing no more than ------ current through them.
   (f) If field coils are dried by passing current through them, current should be left on until ------ values are satisfactory.
   (g) The chemical that may be used to wipe grease off motor or generator windings is ------.
   (h) This chemical creates dangerous fumes, so should not be used in ------ spaces.

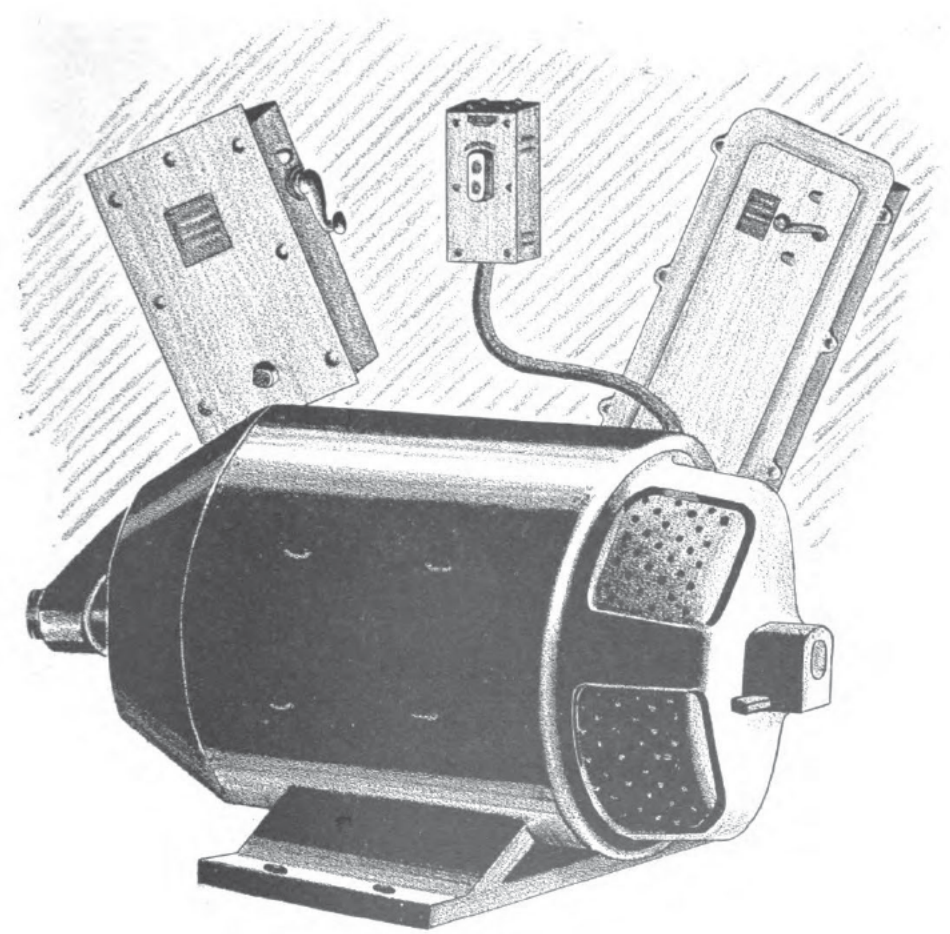
6. Complete the following statements:
   (a) All generators not in use should be turned over ------.
   (b) All idle generators should be run at least 30 minutes each ------.
   (c) All lighting, power, internal communication and fire control circuits should be checked ------.
   (d) Windings of all spare armatures should also be checked ------.
   (e) Once each year
      1. ------ all power from generators to switchboards.
      2. Inspect all ------ from behind.

7. Complete the following statements:
   (a) Before opening electrical cabinets or working on electrical equipment, ------ all power.
   (b) To insure switches remaining open while equipment is being worked on, place ------ on switches.
   (c) Before working on electronic gear, all charge-retaining units should be ------.
   (d) A trouble-shooting chart summarizes the ------ gained by others in locating and correcting casualties.

(e) Before performing tests or repairs, get ------ from your chief EM.

8. In column I below are listed certain electrical casualties: Column II indicates, by trouble analysis chart number, some of the probable causes that were checked. In column III give the trouble analysis chart number of other probable causes you would check to locate the trouble .

I Fault	II Probable causes checked	III Additional causes to check to locate trouble
1. Slight sparking at generator brushes.	1–10; 11A to 11E--	---------------
2. Severe sparking at generator brushes.	13A–13D; 14A, 14B.	---------------
3. Motor or generator armature overheated.	15–19; 21---------	---------------
4. Motor or generator field coils overheated.	22, 23-----------	---------------
5. Motor bearings overheated.	25; 26; 31; 32-----	---------------
6. Noisy generator---------	35–40-----------	---------------
7. Shunt motor speed too high.	44A, 44B---------	---------------
8. Motor speed too low-----	48; 49; 50--------	---------------
9. Motor fails to run-------	53A, 53C, 53D----	---------------
10. Generator output polarity reversed.	58B, 58D---------	---------------
11. Generator fails to build up.	61; 63A–63F; 64; 65.	---------------



CHAPTER 11

DIRECT-CURRENT CONTROLLERS

WHAT THEY DO

A motor controller is a device by which you can safely and conveniently start or stop an electric motor, speed the motor up, slow it down, or reverse it. The controller is connected between the motor and the line and is a unit made up of a main motor switch with some auxiliary devices like relays, resistors, switches, etc., all mounted on a single panel or in a single cabinet.

For small motors you need simple little controllers, which are hardly more than a switch for connecting the motor directly across the line. For big motors you need big controllers that include: big switches to connect the motor to the line; devices for permitting you to start and stop the motor from a distant point; protective devices that prevent

burning out the motor if overloaded or to stop it if power should fail; and devices that automatically control speed of the motor, to give it smooth accleration and smooth stopping.

CLASSIFICATION OF CONTROLLERS

Controllers used in the Navy are generally standard industrial type equipment slightly changed to meet Navy needs. They are of several main types depending on how they work, how they are built, how they are enclosed, and how rugged they are.

HOW THEY WORK—

MANUAL type. In manual type controllers you turn an operating or control lever by hand to start, stop, speed up, slow down, or reverse the motor. See figure 116.

AUTOMATIC type. In automatic controllers the switching operations required for starting, stopping, acceleration control or protection are performed automatically. You press a START or STOP push button and the controller does the rest. See figure 118.

HOW THEY ARE BUILT—

FACE plate type. A face plate controller has a group of contacts arranged as studs on an insulated plate. The control lever has one contact. When the lever is rotated its contact moves over the face of the plate and contacts one stud after another, thereby making the connections required for starting, stopping, speed control, etc. A typical face plate controller is shown in figure 116.

DRUM type. Drum type controllers have a number of fixed contacts arranged like fingers sticking out from one long shaft, and rotating contacts arranged as studs on a cylindrical drum. The contact fingers move over these rotating contacts as the drum shaft is rotated, making the necessary connections for motor starting, stopping, etc. See figure 121–A.

HOW THEY ARE ENCLOSED—

The panels on which controller devices are mounted could be left out in the open but they are usually enclosed, for three reasons: To protect personnel from

touching live contacts; to prevent the start of fires from the hot arcs in the motor switch; and to keep moisture and water from getting at and ruining the controller devices. You will therefore find controllers aboard ship with these types of enclosures: OPEN type. The controller panel is not provided with any enclosure. See figure 116.

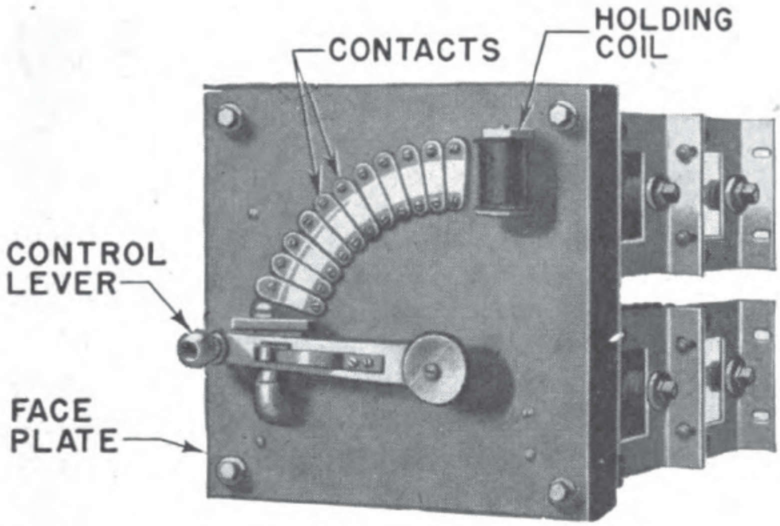


Figure 116.—Open type motor starter

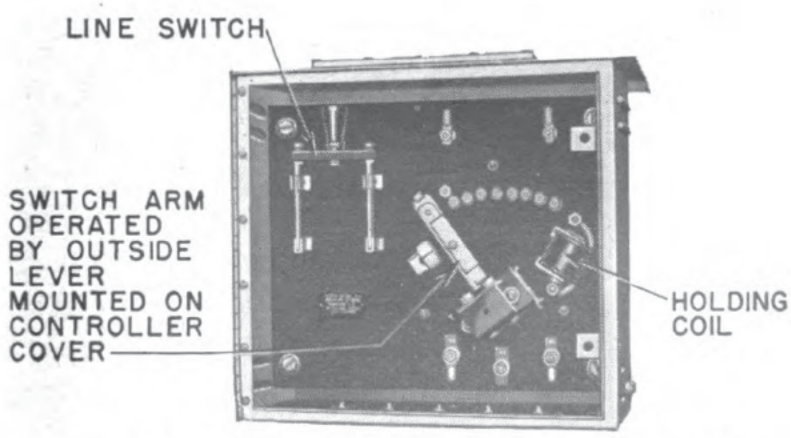


Figure 117.—Semi-protected motor starter or controller.

SEMI-PROTECTED type. Resistors and wiring are mounted on the rear of the panel within a protected enclosure as shown in figure 117.

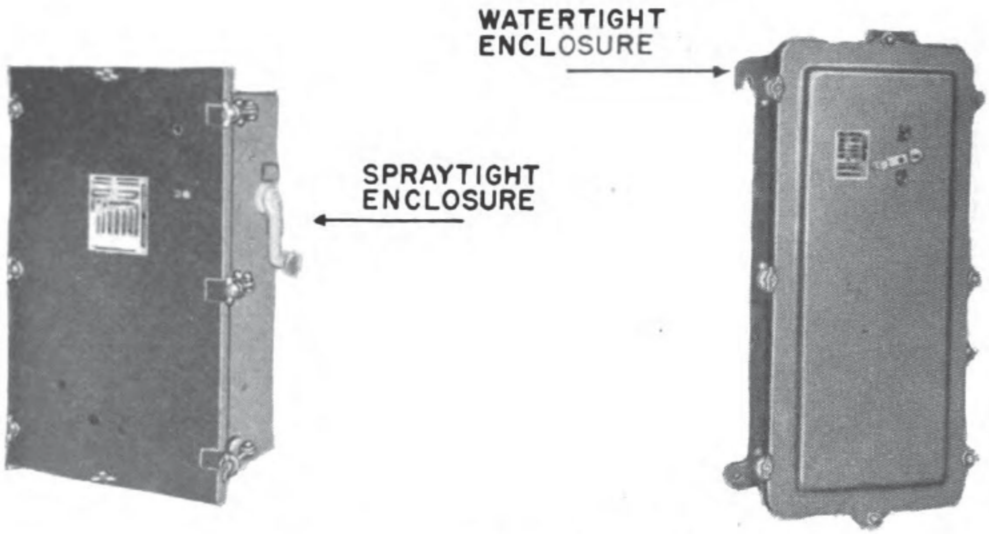


Figure 118.—Motor controller enclosures.

DRIP-PROOF type. In a drip-proof controller the enclosure provides protection against liquid material falling on the controller panel. See figure 118.

SPRAYTIGHT type. Spraytight enclosure is provided by a solid, gasketed case, as shown in figure 118. The controller is thus protected completely against splashing water from the weather or from the stream out of a hose.

WATERTIGHT type. Watertight enclosure will protect the controller when submerged in water up to 15 feet deep.

HOW RUGGED THEY ARE—

In a fighting ship, the controller devices must not break or be accidentally operated by the shocks from the ship's own gun fire, from bomb burst, or from shell hits. The construction of Navy controllers is therefore heavied up to provide the following degrees of shock resistance.

150 FT.-LB. SHOCK RESISTANCE. Controllers of this class are rugged enough to withstand a 150 foot-pound shock without damage or interruption of electrical operation.

2,000 FT.-LB SHOCK RESISTANCE. Many controllers for shipboard use are designed to resist damage and interruption of operation even from a 2,000 foot-pound shock.

CONTROLLER TERMINAL MARKINGS

Before studying the controller circuits you must know the letters used to designate different terminals on a controller. The following list of terminal markings is standard in the Navy.

Line	L_1 and L_2
Armature	A_1 and A_2
Shunt field	F_1 and F_2
Series field	S_1 and S_2
Pilot circuit	P_1 and P_2, etc.
Brake	B_1 and B_2
Commutating field	C_1 and C_2
Armature resistances	R_1, R_2, etc.
Shunt field resistances	V_1 and V_2.

ACROSS-THE-LINE CONTROLLERS

A small motor can be safely started by connecting it directly across the line. Starters or controllers for small motors therefore usually consist of an across-the-line switch, with a fuse in the line as the only means of protection against burn-out of the motor.

FACE TYPE CONTROLLERS

A face type controller is shown in figure 116. This type of controllers, or starters, as they are more commonly called, are used for starting series, shunt, or compound motors. From the schematic diagrams in figures 119, 120 for this type starter you can see how it works. Looking at either one of these diagrams, you see that when the arm is raised to the first contact, *A*, the field is connected directly across the line and the starting resistance is placed in series with the armature. Putting the full line voltage on the field provides a heavy starting torque, and the high resistance in the armature keeps the starting current down to a safe value. The starting resistance is gradually cut out of the armature circuit and placed in the field circuit as the arm is raised.

When the starter arm moves into contact with the holding coil all of the starting resistance is out and the armature is

connected directly across the line. The electromagnet holds the arm in a running position as long as line voltage is maintained. In case the line voltage falls very low or fails altogether, the magnet releases the arm, and the arm is pulled back to the OFF position by a spring. In this way the motor is automatically disconnected when power supply fails, so

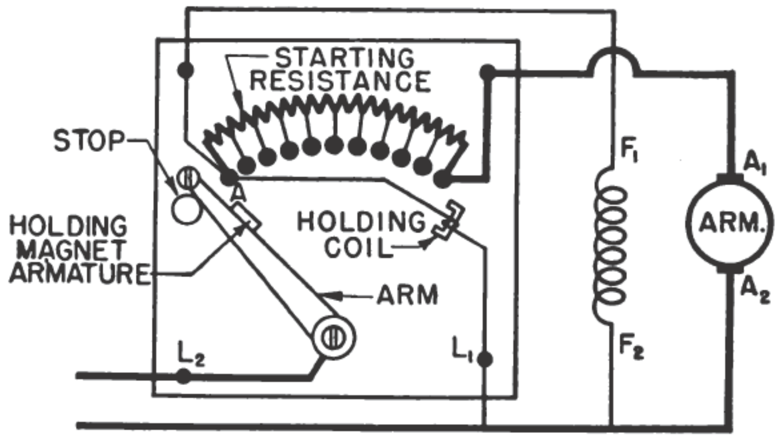


Figure 119.—Schematic diagram for a face type controller.

that it will not be damaged by running on low voltage or by sudden starting when the voltage is restored. This normal type starter may be used with series, shunt and compound motors.

In some starters the low-voltage-release magnet is designed to be connected in series with the shunt field, as shown in

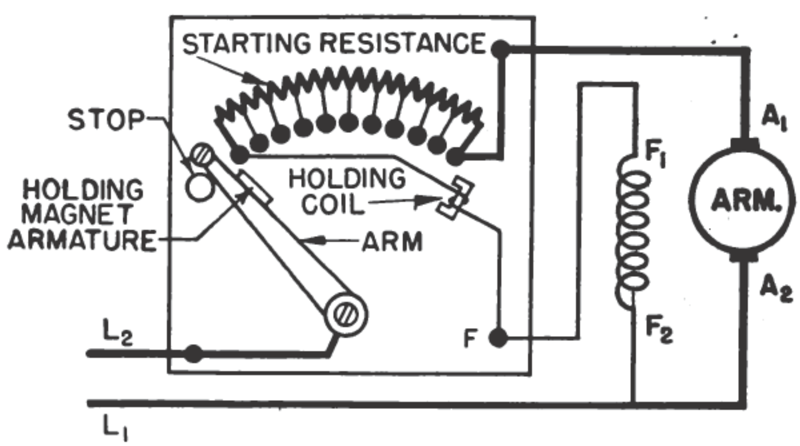


Figure 120.—Schematic diagram for a face type controller with weak-field cutout.

figure 120. With starters of this type the electromagnet will release the arm if the field circuit is opened. This is a

decided advantage, since the armature will be brought to a stand still instead of racing when the field becomes weak due to loss of field current. These starters are used only with shunt and compound motors.

DRUM TYPE CONTROLLERS

A DRUM type controller is shown in figure 121–A. This type is used to start large motors of 12 horsepower or over,

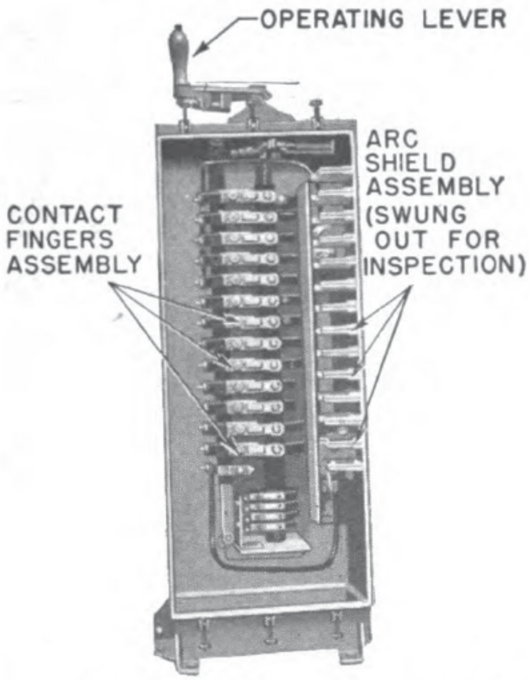


Figure 121–A.—A drum type controller.

and with moderate-sized motors that require frequent starting, stopping, and change of speed. They are extensively used to control motors used in connection with equipment such as deck winches, cranes, and anchor windlasses.

This controller is essentially a drum cylinder insulated from its central shaft and the shaft operating handle. Copper segments connected together or insulated from each other are attached to the drum. A series of stationary fingers are arranged to act as brushes which come in contact with the conducting segments as the cylinder turns. See figure 121–B. The fingers are insulated from one another, but are connected to the starting resistance and other circuits as shown in figure 121–C. Just under the handle a notched wheel

called a detent, is keyed to the shaft. A spring forces a roller into one of the notches as the contacts are made, holding the drum at the selected position and indicating to the operator the position of the handle.

The segments are positioned around the drum so that as the operating handle is rotated further to the left or right of center position the fingers (indicated by dots L_1, R_1, R_2, R_3, etc.) come into positions indicated by dotted lines 1, 2, 3.

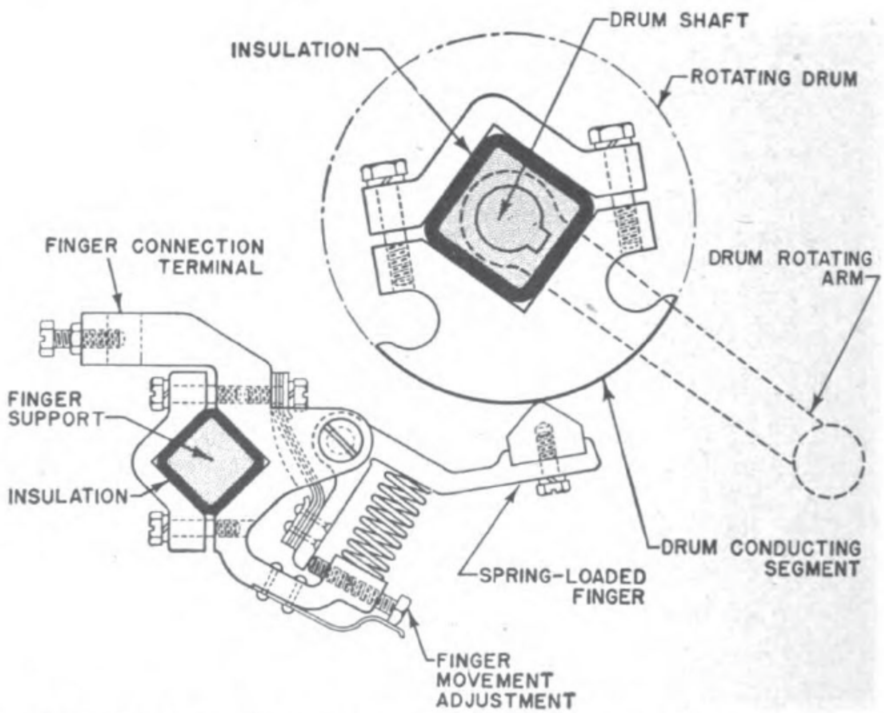


Figure 121–B.—Mechanical arrangement, drum type controller.

In figure 121–C is shown what happens as the controller handle is moved to the left (rotation forward). At first (position 1) a full strength field current is provided to provide full starting torque; and a contact is made to the armature through the full armature resistance, to keep the starting current down to a safe valve. As the drum is rotated further the field contact remains the same, but the armature resistance is cut out gradually until the motor is at full speed.

Reversal is accomplished by turning the drum in the opposite direction past the neutral point. This connects the shunt field circuit the same as before, but the armature circuit is reversed, which reverses the motor.

The formation of arc between the fingers and the segment is overcome by MAGNETIC BLOW OUT COILS. This coil carries the armature current and produces a magnetic field of high

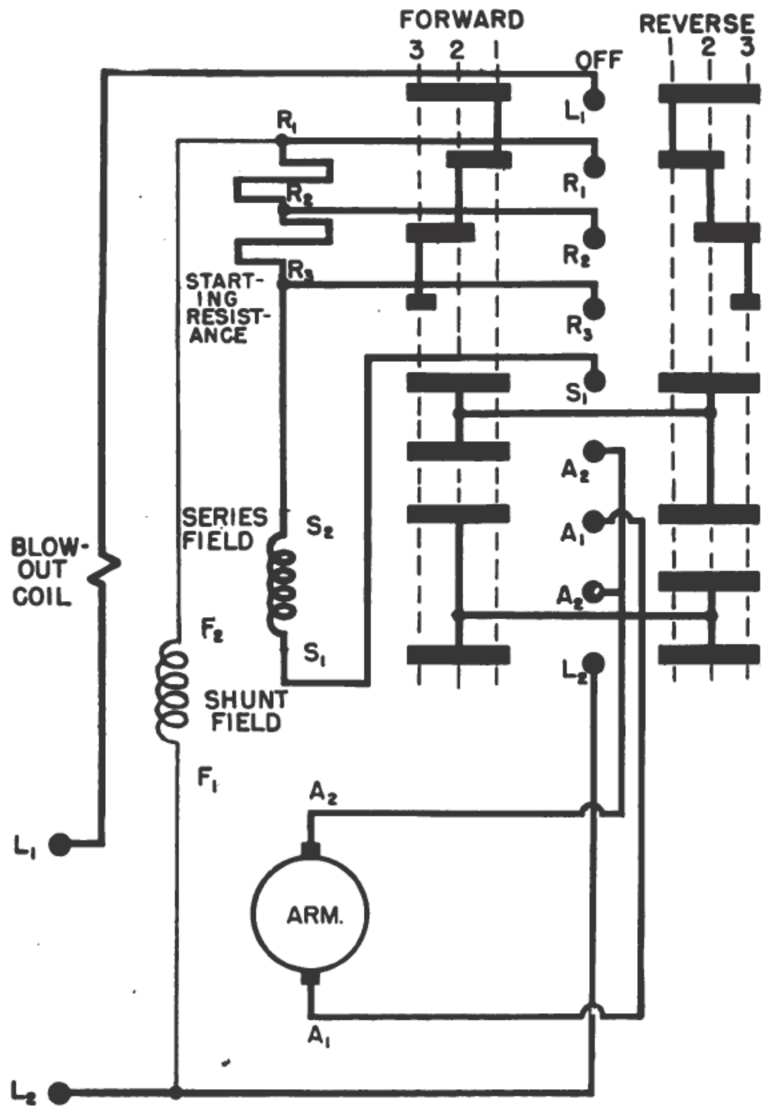


Figure 121-C.—Circuit for a drum controller.

intensity around the tips of the fingers. When a contact is broken and an arc has a tendency to form, the magnetic field will blow the arc out in much the same way as you blow out a candle.

Arc DEFLECTORS are small panels of fireproof insulating material, mounted between the switch poles, to extend out between the fingers. They are provided as an additional

protection against arcing and to provide additional protection and insulation for the contact fingers.

AUTOMATIC CONTROLLERS—MAGNETIC CONTACTORS

AUTOMATIC controllers are also known as MAGNETIC CONTACTOR controllers because the switch which connects the motor to the line is solenoid-operated and is called a CONTACTOR. Magnetic contact controllers usually consist of a 2-pole main line switch, a main line contactor for each side of the line, overload and low-voltage release protection, accelerating contactors, interlocks and auxiliary contacts to provide the service required.

This type of controller is used when it is necessary or desirable to start and stop a motor from some remote point, or when it is necessary to operate a motor from several different places. Controllers of this type are used with such equipment as steering engines and particularly with such

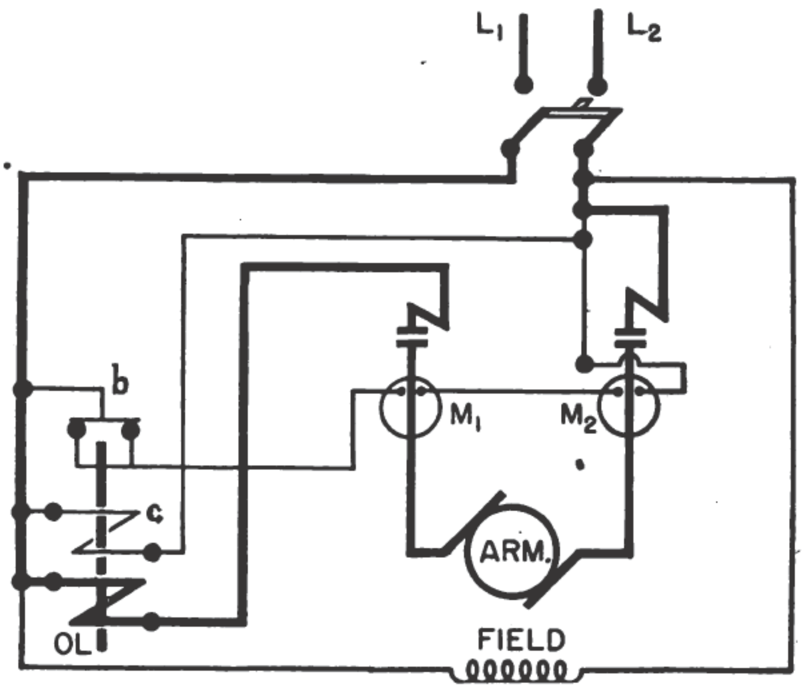


Figure 122.—A magnetic contactor schematic diagram.

motorized mount or turret equipment as elevating gear, training gear, projectile and powder hoist, etc. They are also used in conjunction with drum type controllers and cam-contactor controllers.

In figure 122 is shown a schematic diagram for an automatic controller furnishing current to a motor through two simple line contactors equipped with an overload release. Be sure to note that no fuses are on this panel. The controller includes a knife switch used to disconnect power from the controller. When the knife switch is closed, both the shunt coils of contactors of M_1 and M_2 are energized through the bridge *b*. This bridge consists of two pins connected to coils M_1 and M_2. The metallic plate lying across the tip of these two pins is connected electrically to L_1, and is held upon the pins by the force of gravity only.

When the circuit is closed through the main line contactors, contacts M_1 and M_2 are closed, thereby energizing the motor by current flow from L_1, through the overload coil *OL*, the main contactor M_1, the armature, then back through the main contactor M_2, to the line L_2. Note also that the field coil is energized at the same instant as the contactor coils. With this panel the motor will continue in operation as long as the load current remains normal. If the load becomes excessive, the motor will draw current beyond safe limits and will cause the overload coil *OL* to operate. This overload coil has a few turns of wire sufficiently heavy to carry the armature current. When this coil is energized it tends to draw a plunger up through the core of the coil. If the magnetic attraction is sufficiently great, this plunger will be pulled completely into the coil, and the upper end of the plunger will raise bridge *b*. When this occurs the circuit through the shunt coils of contactors M_1, and M_2 is broken at bridge *b*, opening contacts M_1 and M_2, shutting down the motor.

At this point the HOLDING COIL, *c*, comes into use. This coil is energized as soon as the line switch is closed. The magnetic pull of this coil is in the same direction as that produced by the overload coil *OL*. The holding coil *c* is not strong enough to lift the plunger when the line switch is closed, and therefore will not open bridge *b*. When the line current exceeds a safe value, however, the overload coil lifts the plunger to the point where the bridge *b* is opened, and the holding coil *c* has sufficient magnetic pull to hold the plunger

in the raised position. In this way the holding coil will hold the bridge open after the overload coil has interrupted the circuit.

If it were not for the holding coil, the plunger would drop as soon as the current through the overload were interrupted by the main line contactors. At the instant when the plunger drops to the bottom of its stroke, the circuit through the main contactor and bridge *b* would be closed again, sending current as before through the overload coil and the main contractors to the armature. If the cause of the overload still existed, the overload coil would operate again, interrupting the circuit to the shunt coil as before. This action would result in a continual clattering of the contactors if this type of controller panel were not provided with a holding coil. If an overload does occur, the cause of the overload should be removed and the switch opened, thereby releasing the holding coil *c*. The panel is then ready to operate again.

CLASSIFICATION OF MAGNETIC CONTACTOR CONTROLLERS

With respect to operation of the CONTROL CIRCUIT, magnetic contactor controllers are furnished in the following types: NON-AUTOMATIC (manual); SEMI-AUTOMATIC; FULL AUTOMATIC.

With NONAUTOMATIC control the operator is responsible for and performs all control functions of starting, stopping, and accelerating the motor.

With SEMIAUTOMATIC control, the rate of acceleration at starting is not within the operator's control. It is dependent upon accelerating contactors which are adjusted to function according to predetermined condition of current, voltage, or time.

With FULL AUTOMATIC control, all basic functions including the starting and stopping of the motor are performed without the necessity of any manual operation.

CIRCUIT BREAKERS

Instead of fuses or overload relays, circuit breakers are used for overload protection of very large motors. Circuit

breakers installed in electrical circuits protect the circuit devices automatically against overload by opening the circuit when current drainage becomes abnormally high. The circuit breaker costs more and requires more space than a fuse, but it can operate an infinite number of times without injury. Then, too, the action of the circuit breaker is faster than a fuse; that is, it opens the circuit more quickly.

Practically all circuit breakers operate on the same principle. The mechanism which locks the breaker contacts together is held by a trigger. This trigger is actuated by a plunger in a solenoid. The solenoid itself is in series with the circuit. When the current becomes excessive, the plunger is raised and trips the trigger, allowing the breaker to spring open the circuit. Many breakers also have shunt solenoids which allow them to be tripped from remote points.

The current through the breaker usually is carried by a laminated copper bridge formed of a stack of thin copper strips. On closing the switch, the ends of these bridge strips press on copper blocks, producing a wiping action. The carbon blocks are connected parallel to these copper contacts. Ordinarily they carry a negligible portion of the current, but when the breaker opens, the carbon blocks open contact later than the copper and so they interrupt the arc, which would otherwise burn the copper. The carbon contacts are cheap and easily renewable.

Circuit breakers are supplied for use aboard ship on either alternating or direct current circuits, with voltage from 110 to 450 and currents from 15 to 6,000 amperes. Breakers may be single-, double-, or triple-pole construction and may either be operated manually or electrically. The electrically operated circuit breaker is controlled either by a solenoid or a small motor.

Functionally, circuit breakers are divided into three classed: OVERLOAD, UNDERVOLTAGE, and REVERSE CURRENT. The OVERLOAD circuit breaker is designed so it opens automatically when the current (load) on the circuit becomes greater than some value for which the breaker is set, and which is usually the current which the equipment, or feeders, can safely stand. Overload circuit breakers used with ship-

board equipment have the additional feature of not being susceptable to tripping when subjected to successive heavy shocks, such as caused by gun fire. This type of circuit breaker is used on all rotating electrical machinery and feeders to vital loads, such as turrets and searchlights. This type breaker is also used on the generator switchboards to protect the generators. Overload protection is also provided, by appropriately designed circuit breakers, for instantaneous current (short circuit protection); for thermal overload (to prevent overheating); or for instantaneous current-and-thermal overload, etc.

The UNDERVOLTAGE, circuit breaker is designed to open if the voltage fails or falls below a predetermined value. Contactors or circuit breakers provided on all motor control panels have this feature.

The REVERSE CURRENT circuit breaker is designed to open any time that the direction of current flow changes. It does not open if the current fails. The reverse current circuit breaker has widest application on storage battery charging panels. Another application is with paralleled generators. In both these cases it is necessary to prevent the current flowing in the reverse direction from what it does normally, to prevent damage to the equipment.

PRECAUTIONS—CONTROLLERS

SWITCH AND LEVER OPERATION. Watch the contact points when operating switches or rheostats. Heavy sparking, indicating poor or broken contact, should be investigated and remedied at once. In opening field switches, the blades should be drawn out slowly, allowing the field to discharge with a drawn-out spark. This will prevent the establishment of a high self-induction potential in the field coils which might break down a weak point in the winding's insulation.

HEAT AS A TROUBLE INDICATOR. The operating personnel should be on the alert constantly for the presence of unusual or unexplained amount of heat around the control panel. Heat is the primary symptom of electrical trouble. (See chapter 10.) If excessive heat is noticed about the controller

panel, one of two conditions is usually indicated; either the line leads to or from the panel are too small in current carrying capacity, or a loose or insufficient contact exists at some connection point. A loose contact, especially when cable attachments are made, generates heat in considerable quantity, and will lead to a casualty unless the condition is remedied. Such trouble usually can be traced by finding the location of greatest heat.

OVERLOAD BLOWOUT. If, on starting a motor equipped with a drum type controller, fuse or circuit breaker goes out due to an overload, be sure to move the controller arm to the OFF position before renewing the fuse or resetting the circuit breaker.

STARTING RESISTANCE LEFT IN. When a motor is started by an automatic contactor controller, the operator should determine, after starting the motor, that all the starting resistance has been cut out before leaving the panel. If all the accelerating contactors do not close, the condition probably will be indicated by the failure of the motor to build up to its normal speed. Failure of one of these contactors to close will leave some of the starting resistances in the armature circuit. If left in, they will soon overheat and burn out.

USE OF WIRING DIAGRAMS. Large motors, such as those used for anchor gear, steering gear, capstans, and boat cranes usually are operated by a master distant controller. It is necessary that personnel handling equipment of this type be thoroughly familiar with the wiring diagrams of the control circuits. These diagrams generally contain a table giving the contactors which should be closed for various positions of the master controllers. Intelligent use of this table will make it possible to trace trouble easily. See chapter 10.

PANEL DOORS. The panel doors should be kept closed at all times unless the contactor actually is being worked on. In the case of water-tight controllers make sure the doors are fastened securely before leaving.

CARE AND REPAIR OF CONTROLLER PANELS

Controllers of the panel type should be "whisked" off frequently with a brush called a PAINTER'S DUSTER. This

brush has no metallic binding, and is made of soft bristles about four inches long. If it is necessary to clean off anything other than dust, use a soft flannel rag or piece of chamois skin. Frequent examination of all connections shall be made to insure they are tight. *CAUTION*: BE SURE ALL POWER IS OFF BEFORE WORKING ON CONTROLLER PANEL.

Panels are often placed so that the back of the panel is inaccessible for ready examination. In such cases, the heat test may be relied upon to indicate trouble; but as soon as heat is discovered, the panel should be pulled down to find and remedy the trouble. The condition of the wires behind the board should be investigated as often as possible. The tendency of the ship's structure to weave sometimes will cause enough movement of the panel wires to produce abrasion and subsequent breakdown.

If it becomes necessary to remove moisture from a panel, use a flannel cloth, and subject the panel to a baking process if the damage is serious. Remember that surface moisture is a conductor, and its presence on a panel often will account for low circuit insulation resistance readings.

CARE OF PANEL DEVICES

OVERLOAD AND LOW-VOLTAGE RELEASE DEVICES. Adopt a routine inspection for over-load and low-voltage release devices. Keep the spring on the starting rheostat arm strong enough to throw the lever to the OFF position in the event of voltage failure.

Keep contact buttons tight, clean and of uniform length. If they are burned badly, replace them. See that sliding contacts are smooth and bear evenly on the contact buttons.

The overload- and low-voltage release armature hinge pins, the starting lever shaft, and the solenoid contact blocks should be removed occasionally and cleaned with fine sand paper. If this apparatus is kept bright and free from dirt and paint, there is little opportunity of its sticking.

OIL. The USE OF OIL AROUND ELECTRICAL PANELS and equipment usually IS DANGEROUS because inexperienced personnel become careless. Oil also creeps and collects

dirt, thus forming current leakage paths which eventually result in breakdown of the panel's insulation resistance.

SWITCHES. Switch clips should be kept smooth and tight to insure good contact when closed. Loose and dirty switch clips will cause an increase in temperature and eventually burn the fouled areas.

CIRCUIT BREAKERS AND CONTRACTORS. Examine circuit breakers and contactors frequently to see that the contacts are in proper condition and that all connections are tight. Should the contacts be burned, smooth them down with a file or renew them as needed.

Laminated brushes should be lubricated with a light film of vaseline, and hinge pins with a few drops of medium oil. No lubrication should be used on the carbon arc-rupturing contacts. See that the levers work freely, and that no tendency to stick is present which could prevent the circuit breaker or contactor from opening.

RHEOSTATS. Rheostats are more subject to short circuits than any of the other panel accessories. They shall be kept dry and as free of dust and dirt as possible. Wipe off the exposed molded insulation surfaces frequently. If these surfaces break or crack, renew them. If the rheostat gets wet, it shall be wiped carefully and dried before being put in service again. If convenient, it should be dried in a warm compartment, but if this isn't possible, then it may be warmed slowly by allowing a low current to pass through the windings until all moisture has been expelled. Start with about one-fourth of the rated current and, as the rheostat warms up, if no trouble develops, gradually increase the current until full rated current is allowed to flow. This condition should continue until the insulation readings are one megohm or better. To remove dust and dirt use the painter's duster. Use a bellows or a blast of DRY air to reach the inaccessible parts.

CARE OF DRUM CONTROLLERS

Care must be taken when examining controllers of the drum type to see that cover gaskets are not broken or damaged, and that they seat all around with a good contact. With weather deck controllers, special care shall be exercised to

keep packing boxes and stuffing tubes well packed. Covers removed for inspection shall be replaced at once. Keep polished steel surfaces covered with a heavy grease, to prevent rust and corrosion. Lubricate the shaft bearings with a small amount of heavy oil.

Trouble will develop occasionally from grounding of the blow-out or arc-rupturing coils, since these coils aften are subjected to excessive moisture and dampness. Their inaccessiblity causes them to be neglected. For this reason particular attention should be given to keeping the base of the controller housing tight and free from moisture.

CARE OF DRUM CONTROLLER DEVICES

Controllers shall be examined frequently enough to insure smoothness and even bearing of the fingers and contacts. Any roughness shall be smoothed up with a file, and if the condition is bad the part shall be renewed. Fingers shall be kept in adjustment so that as the segments pass underneath them, they will lift about one-sixteenth of an inch. Always examine the fingers of deck controllers after heavy gun fire. Unless they should be of a special design, they will tend to loosen and drop off their normal contact. Lubricate bearing surfaces with a light film of vaseline. The star wheels on the controller shaft are often neglected. Wheel and detent shall be kept free of dirt and verdigris, and kept coated with a light coat of grease or vaseline. Keep inflammable materials away from arc deflectors. *CAUTION:* DISCONNECT ALL POWER TO CONTROLLER BEFORE WORKING ON DRUM CONTROLLER.

GENERAL CARE OF AUTOMATIC CONTROLLERS

The very fact that a panel is automatic in its action is apt to result in its neglect. A little thought on the subject will show that by its nature it should be subjected to frequent, periodic and rigid inspection. Wiring diagrams should be available, as the circuits are complicated enough to justify special study. Thorough familiarity with the sequence of operations often will save valuable time at moments of critical breakdowns.

CARE OF AUTOMATIC CONTROLLER DEVICES

Keep the main and auxiliary contactor contact surfaces clean and bearing uniformly. Keep the auxiliary contact impact springs at an even tension, and renew those that are defective. Give the protection devices (overload and no-voltage devices) a frequent inspection and test. On these tests note the proper operation and sequence of the contactor. The omission of a minor repair or adjustment to one contactor will often disable the panel.

Keep the flexible contactor terminals tight and watch for other chances of open circuit in the control circuits. See that the flame deflectors are properly placed to prevent a spreading arc, and keep inflammable material away from them. Keep the panel clean and dry. Lubricate sparingly, especially at the hinge pins of contactors, levers, and armature, taking care to wipe off all excess oil. *CAUTION*: DISCONNECT ALL POWER TO PANEL BEFORE WORKING ON AUTOMATIC CONTROLLERS.

PANEL SURFACES

Surface moisture must be kept at a minimum on panels of all descriptions. The USE OF ALCOHOL for cleaning panels IS DANGEROUS and shall not be allowed. Not only is it an inflammable material, but it will break down the finished surfaces of the panels and of the instruments on them, and thereby ruin their insulation resistance.

FUSES

Fuses can be a considerable source of trouble if they are not installed and replaced intelligently. They always should have the current capacity of about one-fourth in excess of the normal load current they are designed to pass, and should never be installed haphazardly. Unless an immediate emergency exists, the blowing of a fuse should always be investigated to determine the cause of the overload. Using fuses of higher capacity or increasing circuit-breaker settings without investigating for the trouble on the defective circuit cannot be disapproved too strongly.

QUIZ

1. Complete the following statements:
   (a) A motor controller is a switching device for starting or stopping a motor and
      1. ______ motor speed.
      2. ______ motor rotation.
   (b) Controllers may also contain devices to protect the motor against
      1. Burn out if ______.
      2. Damage if power ______.
   (c) In manual controllers motor starting and stopping is performed ______ by the operator.
   (d) In automatic controllers motor starting and stopping is performed ______ by electrical devices.
   (e) In a face plate controller the circuit connections are changed by a rotating control arm moving over ______ contacts.
   (f) In a drum controller circuit connections are changed by contacts on a drum rotating past stationary ______.
   (g) Motor controllers are enclosed in order to:
      1. Protect personnel from ______ contacts.
      2. Prevent start of fires from hot ______ in motor switch.
      3. Prevent moisture ______ to controller elements.
   (h) The ability of controllers to withstand gun fire recoil, bomb bursts and shell hits is indicated by the ______ rating.
   (i) In d-c controllers, the terminal markings
      1. ______, ______, stand for line connections.
      2. ______, ______, stand for armature connections.
      3. ______, ______, stand for shunt field resistance connections.

2. Complete the following statements:
   (a) Across-the-line starters are used for controlling ______ motors.
   (b) In face plate controllers, the motor is kept across the line while power is on, and is taken off the line when power fails, by an ______.

(c) A face plate controller with weak-field release ------ the motor when field current fails.

(d) Weak-field release is used to prevent motor ------ if field current fails.

3. Complete the following statements:

(a) Drum type controllers are used to control large motors that require ------ starting and stopping.

(b) In drum controllers, reversing movement of the handle from neutral ------ motor rotation.

(c) In drum controllers, damage by arcing is reduced by

1. Magnetic blow-out ------.
2. ------ deflectors.

4. Complete the following statements:

(a) In ------ controllers the motor is connected across the line by a solenoid operated switch.

(b) The solenoid operated switch permits starting the motor from

1. a ------ point.
2. ------ places.

(c) After a circuit has been interrupted by the overload coil, it is kept open by a ------ coil.

5. What procedure is required to restore an automatic controller to operation after the motor has been cut off due to overload?

6. Complete the following statements:

(a) If motor starting, stopping and acceleration are all performed automatically the motor controllor is called ------.

(b) If motor starting and stopping are performed automatically but the operator controls motor acceleration, the controller is called ------.

(c) With ------ controllers the motor is started, stopped, and accelerated by the operator.

7. Complete the following statements:

(a) A circuit breaker protects a circuit against overload ------ than a fuse.

(b) Circuit breakers may be operated from remote points by ------.

(c) The carbon contacts in circuit breakers prevent ______ of the copper contacts.

(d) Circuit breakers may be designed to interrupt the circuit when:

1. ______ falls too low
2. ______ reverses

8. Complete the following statements:

(a) Opening a field switch slowly prevents breakdown of ______ insulation.

(b) Heat in an indicator of ______ in controller panels.

(c) In an automatic controller, if accelerating contactors fail to ______ the starting resistors are left in circuit too long and burn out.

(d) Oil is dangerous to use on control panels because it forms ______ which cause breakdown of the panel's insulation resistance.

(e) If drying a resistor by passing current through it,

1. Start with ______ of rated current.
2. Increase up to ______ rated current.
3. Continue current until insulation resistance is over ______.

9. Complete the following statements:

(a) Particular care should be used to keep open-deck-mounted controllers water ______.

(b) Fingers of drum controllers should be adjusted so drum contacts raise them ______ inch.

(c) Drum controller fingers should always be checked for tightness after ______.

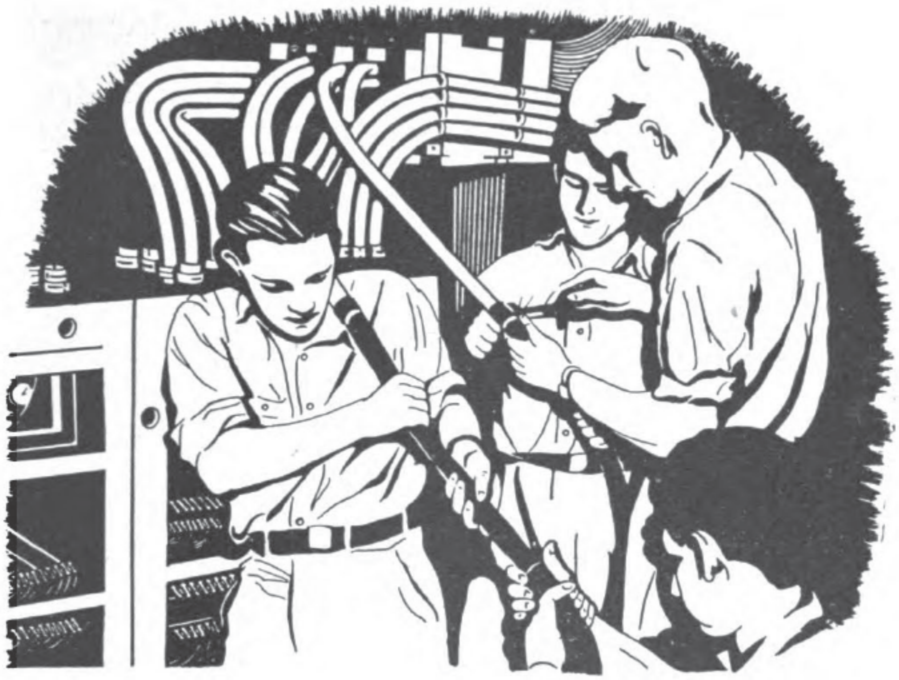
(d) The principal precaution in working on controllers is to ______ all power before working on them.

(e) Use of alcohol in cleaning controller panels is dangerous because

1. Alcohol is an ______ material.
2. Alcohol breaks down panel finishes and thereby ruins their ______.

(f) Fuses should never be replaced with those of ______ than correct rating.

(g) Circuit breakers should never be reset to ______ than correct rating.



CHAPTER 12

CABLES

GENERAL CLASSIFICATION

Many types of cables are used in the Navy and cables of each type may vary greatly in size. A WIRE is a slender rod or strand of drawn metal. A CONDUCTOR is a wire or combination of wires not insulated from each other. A CABLE is a conductor or group of conductors insulated from each other but within a single casing. A CORD is a small cable, very flexible and insulated to withstand wear of bending back and forth. A DUPLEX CABLE consists of two conductors, insulated from each other, twisted together and incased in one common sheath. A TRIPLEX CABLE is a cable composed of three individually insulated conductors. A MULTICONDUCTOR CABLE is one that has several conductors insulated from each other.

Conductors are made of soft annealed round copper wire, continuous in length and without welds or joints of any kind. Each wire is uniform in cross section and free from all imperfections.

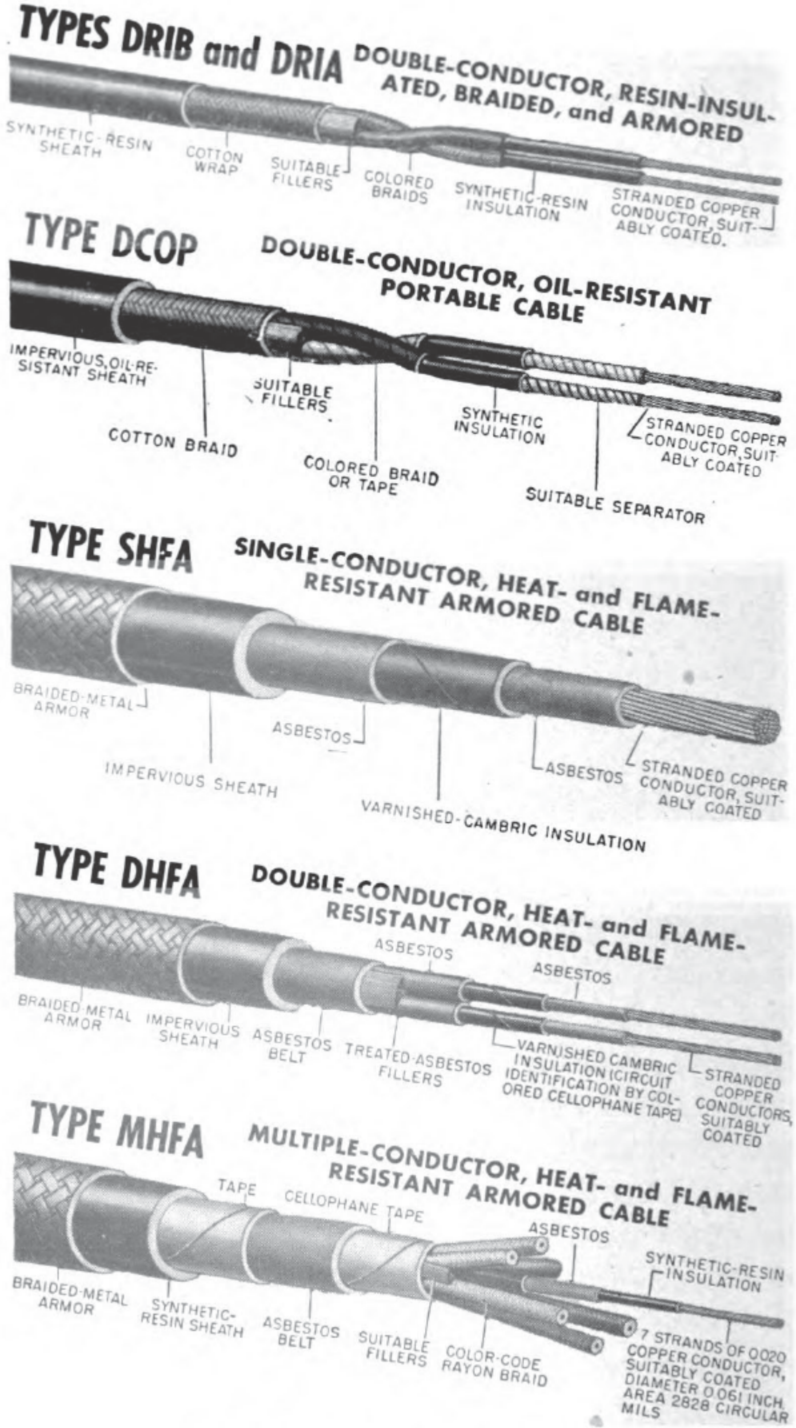


Figure 123.—Cable insulations.

NAVY CABLES

All cables used by the Navy are classified in accordance with the TYPE OF INSULATION used and the general features of their CONSTRUCTION.

The five general insulation classifications, all shown in figure 123 are:

RUBBER INSULATED cables for FIXED installations.

RUBBER INSULATED cables and cords for FLEXIBLE use.

VARNISHED CAMBRIC insulated cables.

HEAT and FLAME RESISTANT cables.

SILK, COTTON, and ENAMEL insulated cables, cords, and wires.

All cables are identified by a standard system of lettering. By using these letters the type of cable covering, type of cable insulation, and number of conductors in the cable can be read easily. A number following the letters generally designates the size, to nearest number of thousands, of circular mils area of the conductor but may stand for the number of conductors or the number of twisted pairs. A number in parentheses following the first number represents the number of strands in the conductor.

Here is an example. A cable has a marking of—

DHFA–4(7). It means

D—The number of conductors—(Duplex)—Two.

HF—Type of insulation—(Heat and flame resistant).

A—Type of cable covering—(Armored)—Usually a braided metal sheath.

4—Total number of circular mils in thousands of all conductors (4 thousands).

7—Tells the number of strands in each conductor.

And another illustration. The cable is marked MHFA–19. It means

M—Multiple—(Having more than one conductor).

HF—Type of insulation—(Heat and flame resistant).

A—Type of covering—(Armored).

19—Indicates 19 conductors within the cable.

The following is a list of standard Navy cables including type designation, size, and permissible voltage-current designations. A study of this table will help you familiarize yourself with the Navy cable marking system.

COMMON TYPES OF CABLES USED IN NAVAL SERVICE

MARKING	SIZE (in circular mils) AND TYPE	VOLTAGE	AMPS
DCOP–3	2613, Duplex, Oil-resistant, Portable.	600	8
DCOP–4	4121, Duplex, Oil-resistant, Portable.	600	11
DCOP–9	9045, Duplex, Oil-resistant, Portable.	600	20
TCOP–2	1608, Triplex, Oil-resistant, Portable.	300	5
TCOP–3	2613, Triplex, Oil-resistant, Portable.	600	6
TCOP–4	4121, Triplex, Oil-resistant, Portable.	600	9
TCOP–9	9045, Triplex, Oil-resistant, Portable.	600	16
FCOP–3	2613, Four conductor, Oil-resistant, Portable.	600	5
FCOP–4	4121, Same type as above	600	11
FCOP–9	9045, Same type as above	600	18
DHFA–3	2828, Duplex, Heat-, Flame-proof, Armored.	600	12
DHFA–4	4497, Duplex, Heat-, Flame-proof, Armored.	600	20
DHFA–9	9016, Same type as above	600	41
DHFA–14	14340, Same type as above	600	55
DHFA–23	22800, Same type as above	600	72
THFA–3	2828, Triplex, Heat-, Flame-proof, Armored.	600	64
THFA–4	4497, Same type as above	600	17
THFA–9	9016, Same type as above	600	36
THFA–14	14340, Same type as above	600	47
THFA–23	22800, Same type as above	600	38
FHFA–3	2828, Four-conductor, Heat-, Flame-proof, Armored.	600	8
FHFA–4	4497, Same type as above	600	17

MARKING	SIZE (in circular mils) AND TYPE	VOLTAGE	AMPS
TTHFA–1	642 One pair twisted telephone. TTHFA are used in the following pairs: 3, 5, 10, 15, 20, 30, 40, 50, and 60:	60	
MHFA–2	2828, Multiple, Heat-, Flameproof, Armored, 2-conductor.	600	6
MHFA–4	2828, Multiple, Heat-, Flameproof, Armored, 4-conductor.	600	6
MHFA–7	2828, Multiple, Heat-, Flameproof, Armored, 7-conductor.	600	6
MHFA–10	2828, Multiple, Heat-, Flameproof, Armored, 10-conductor.	600	6
MHFA–14	2828, Multiple, Heat-, Flameproof, Armored, 14-conductor.	600	6
MHFA–19	2828, Multiple, Heat-, Flameproof, Armored, 19-conductor.	600	6
MHFA–22	2828, Multiple, Heat-, Flameproof, Armored, 22-conductor.	600	5
MHFA–24	2828, Multiple, Heat-, Flameproof, Armored, 24-conductor.	600	5
MHFA–26	2828, Multiple, Heat-, Flameproof, Armored, 26-conductor.	600	5
MHFA–30	2828, Multiple, Heat-, Flameproof, Armored, 30-conductor.	600	5
MHFA–37	2828, Multiple, Heat-, Flameproof, Armored, 37-conductor.	600	5
MHFA–44	2828, Multiple, Heat-, Flameproof, Armored, 44-conductor.	600	4

SELECTION OF CABLE SIZE

If you are to install a circuit, the size of wire should be the smallest possible and still not offer too great a resistance. If the wire size is too large the resistance will be small but the cost of installation will be excessive.

The maximum allowable voltage drop on a wiring system for power or lighting is 5% of the bus bar voltage of the nearest generator switchboard. This drop provides for the loss of voltage in forcing the current through the resistance of the wires from the switchboard to the motor and back again to the switchboard. Do not forget the RETURNING conductor in making calculations. The current must flow through it also.

HOW LARGE A CONDUCTOR

In order to calculate the size of wire necessary for a job, you must know the number of amperes, the length of the circuit and the allowable voltage drop.

The resistance of a wire varies directly as the length and inversely as the cross section area. A copper wire 1 mil in diameter and 1 foot long has a resistance of 10.8 ohms. Since the cross section area, in circular mils, is the diameter, in mils, squared (cm=d×d), the resistance of a length of wire of copper may be found by using the following formula:

$$R=\frac{\text{Length in feet}\times 10.8}{(\text{Diameter in mils}\times(\text{diameter in mils})}$$

The letter R represents the ohms of resistance. The constant 10.8 is equal to the circular mils necessary for a resistance of 1 ohm in a wire 1 foot long.

When the constant, 10.8, is multiplied by the current, you will have the wire size necessary to produce a one-volt-per-foot loss. Now if you multiply the wire size by the length of the conductor and then divide this product by the PERMISSIBLE VOLTAGE DROP, the quotient will be the WIRE SIZE required for a particular installation. Here are the above words in a formula—

$$\text{Area in circular mils (cm)}=\frac{L\times 10.8\times I}{E}$$

Where: L=The length of the conductor in feet.

I=The current flowing.

E=Permissible voltage loss.

Remember the permissable voltage loss is 5% of the bus voltage.

Here is a typical problem: You have a motor drawing 30 amperes. The motor is located 200 feet from a 440-volt bus bar. What is the minimum size in circular mils (cm) of the cable that can be used? First remember that the cable must run to the motor and back to the bus, so L will be 200×2. Now substitute—

$$Cm = \frac{200 \times 2 \times 10.8 \times 30}{440 \times .05}$$

$$Cm = 5890.9$$

Any cable SMALLER than 5890.9 circular mils will have a voltage drop greater than 5%, and any cable larger will have a drop less than 5%. After checking the Navy cable list, the nearest stock size is 4497 cm and the next largest is 9106 cm. The smaller will cause too large a voltage drop so it is unsatisfactory. In this case you will use the larger. More information may be obtained on the various types of cables from the *Cable Comparison Guide, NavShips—250–660–23.*

SHIPS' WIRING SYSTEMS

Ships' wiring systems have to be especially protected against constant exposure to moisture from sea air, against continuous vibration from the engines, and against the severe shocks from gunfire. You will therefore, find the electrical wiring of each ship to consist of the following in addition to the cables:

JUNCTION BOXES. Cable junctions and branch-offs are not made by splices. Instead all cable junctions are made at junction boxes located at convenient points. Each junction box provides a housing, usually watertight, for terminal boards. Conductors are joined individually by connecting to separate terminals on these boards. Junction boxes sometimes also house fuses, small transformers, etc., to provide convenient, accessible location for these elements. A typical junction box is shown in figure 124.

STUFFING TUBES. Cables pass through bulkheads, decks, and into units through special packing glands known as STUFFING TUBES or TERMINAL TUBES. Watertight integrity at the opening through which the cable passes is secured by the action of this gland tightly packing a wax-treated strip of cloth or cord around the cable. Where used to lead a cable into a unit they not only seal off the entry but also insure against disturbance of internal connections. Figure 125 shows a typical terminal tube.

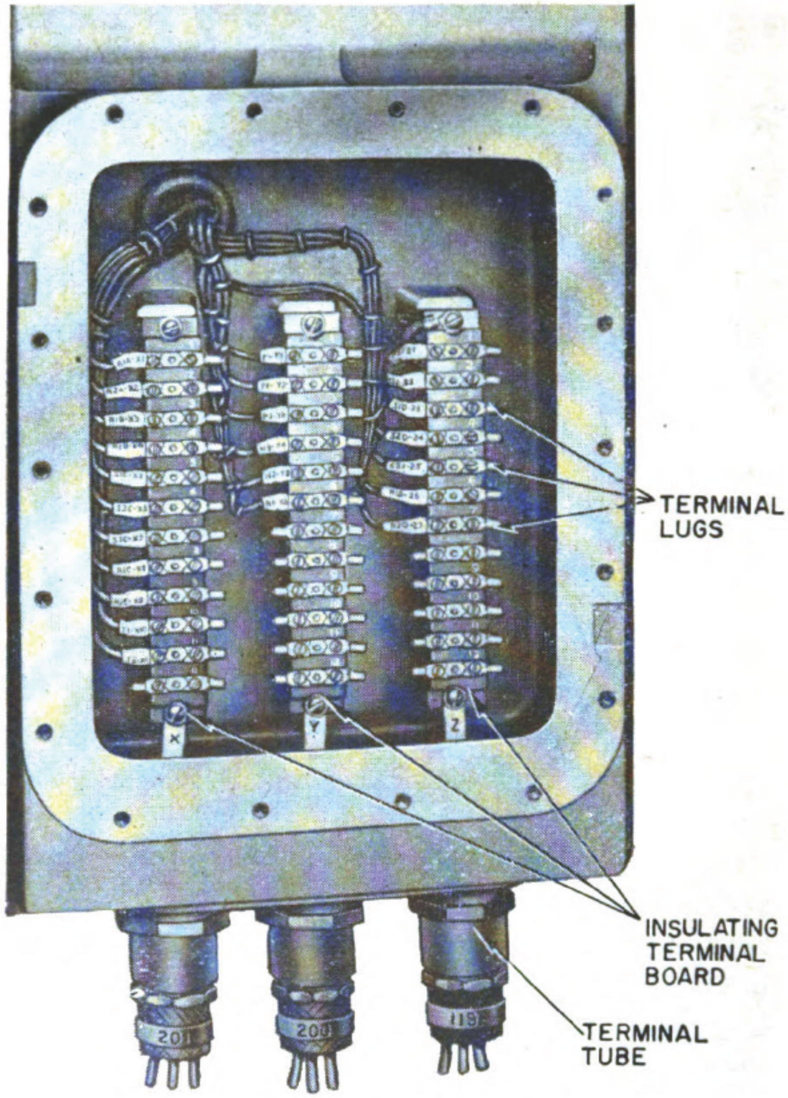


Figure 124.—Electrical junction box.

TERMINAL BOARDS. The profusion of terminal boards in the modern shipboard electrical equipment may at first glance tend to confuse or perhaps overawe the Electrician's Mate with the apparent complexity of the electrical installation. These boards are present to make possible the arrangement of branch circuits through the units and to provide test points. They make it possible, for example, to connect a 20-conductor cable entering the unit to be connected to three or four other five-conductor cables. The typical board mounts at least two rows of binding posts. See figure 124. These double-post boards accept double perforated

lugs and by this arrangement prevent the rocking of adjacent lugs together in the event the tightening nuts have loosened somewhat by vibration. The electrician's mate should be acquainted with the location of every terminal

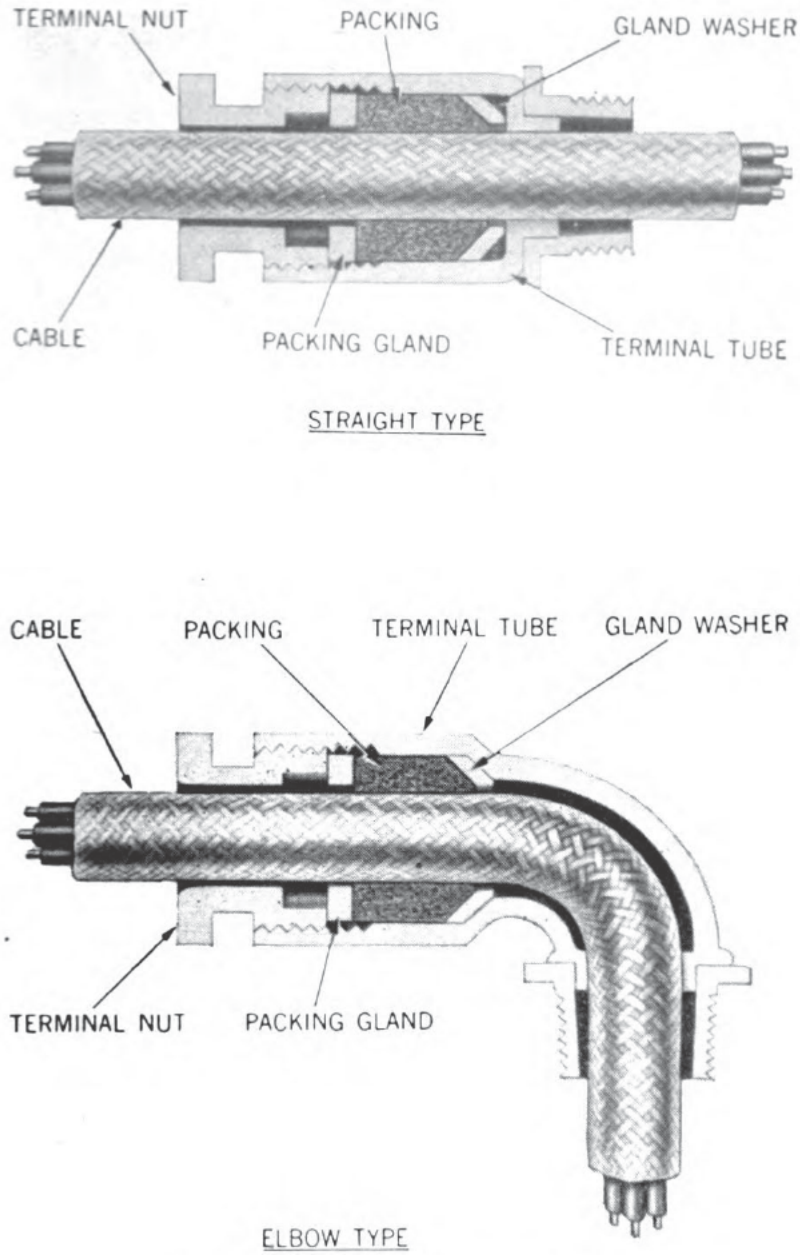


Figure 125.—Typical terminal tube.

board in his equipment for the all important purpose of periodic tightening up. Pliers or similar tools should not be used for this purpose as the binding post screws or nuts

become scarred and wear down to a point where it is impossible to continue the tightening up process.

Terminal boards should always be kept clean and free from danger of formation of shorting paths. The distance between posts is small and especially vulnerable to shorting by loose lockwashers, bolts, and other metallic objects floating in the equipment. The most dangerous object in an equipment is a nut or washer that has been dropped within; for if not retrieved, vibration and movement of the ship will cause it to float around the gear until it causes damage. Experienced men have spent hours recovering objects accidentally dropped, because they realize the damage these loose objects may cause. The careful EM will keep in mind that although a short or shorting object may be a small thing in itself, the current surges that attend it often ruin large transformers and other major components of the gear.

TURRET WIRING SYSTEMS

Turrets have their own very elaborate power, lighting, and communication wiring systems which are particularly well protected against moisture, vibration, shock and fire. The rest of a ship's electrical installation is under cognizance of the Bureau of Ships, but electrical equipment and wiring systems in turrets and mounts come under the Bureau of Ordnance. The BuOrd instruction manuals on mounts and turrets (Ordnance Pamphlets) therefore describe and give complete instructions for the upkeep of turret wiring systems. See your gunnery officer for these books and study their electrical chapters. If you do, you will find your duties in the upkeep of turret or mount electrical equipment a simple, easy job rather than a bewildering, difficult duty.

WIRING PRECAUTIONS

1. CABLE MUST BE SECURED to deck and bulkhead BY standard CABLE CLIPS. All work must be neat and be certain you have not drilled or burned through water-tight bulkheads.

2. When cable is passed through thin bulkheads or beams,

the CABLE HOLE MUST BE ROUNDED OFF or fitted with bushing TO PREVENT CHAFING the cable. When CABLE is PASSED THROUGH a DECK the cable MUST BE PROTECTED BY A KICK PIPE forming part of the stuffing tube and must extend at least 18 inches above the deck.

3. NEVER DRILL OR BURN THROUGH A DECK or bulkhead WITHOUT proper AUTHORITY and then only after examining the other side of that deck or bulkhead for cables or things that might be injured by the drilling.

4. NEVER INSTALL a CABLE WITHOUT FIRST thoroughly EXAMINING the LOCALITY through which the CABLE MUST PASS. A little care will eliminate danger from overheating, from dripping water, from steam or oil lines.

5. Always RUN a CABLE ALONG a BULKHEAD in preference to an overheated run.

6. WHEN a CABLE must be installed where it WILL BE SUBJECTED TO MECHANICAL INJURY, always PROTECT it WITH a suitable METAL CASING.

7. NEVER INSTALL a CABLE USING a SHARP BEND. Always provide a minimum radius of 12 cable diameters if the cable has varnished cambric insulation and 6 cable diameters if the cable has rubber compound insulation for all bends.

8. ALWAYS SEAL the OPEN END OF A CABLE to prevent entrance of moisture.

9. If any other lead is practicable, ELECTRIC CABLE SHALL NOT BE LED INTO OR THROUGH SPACES WHERE any EXPLOSIVES ARE STOWED or spaces adjacent to these storage spaces.

10. When ELECTRICAL CABLE is RUN THROUGH STORAGE SPACES FOR EXPLOSIVES, they MUST BE OF UNBROKEN LENGTH up to the fixture at which they terminate. Unbroken lengths of cable may be run between fixtures.

11. No fuse BOXES, junction boxes, connection boxes, or distribution boxes SHALL BE INSTALLED IN MAGAZINE storage SPACES, except in turret base castings.

12. The ENTIRE WIRING INSTALLATION ON DESTROYERS MUST BE WATERTIGHT unless otherwise specified.

13. ALL FIRE CONTROL CIRCUITS of any ship MUST BE WATERTIGHT.

14. ON SUBMARINES, all LIGHTING, POWER and INTERIOR COMMUNICATIONS CIRCUITS within the interior MUST BE WATERTIGHT for those portions which are BELOW the FLOOR PLATES or normal deck level.

15. All INTERIOR COMMUNICATION CIRCUITS which are VITAL TO THE SHIP in action MUST BE WATERTIGHT.

16. The WIRING installation IN any COMPARTMENT which ordinarily is SUBJECTED TO MOISTURE, PAINT FUMES, ACID FUMES OR SWEATING MUST BE WATERTIGHT.

17. WIRING installation ON MOTOR BOATS MUST BE WATERTIGHT throughout.

18. Always FUSE a LIGHTING OR POWER CIRCUIT AT the point of JUNCTION TO a FEEDER.

19. In general, the rated CAPACITY OF A FUSE for lighting and power system feeders and mains SHOULD BE ONLY TWENTY-FIVE PERCENT GREATER THAN the NORMAL LOAD on the circuit. Exceeding this capacity will endanger the circuit. Less than this capacity will cause the circuit fuses to blow. The CAPACITY OF a FUSE SHOULD BE GREATER THAN the SETTING FOR an OVERLOAD RELAY in that circuit.

20. When USING ALUMINUM TERMINAL TUBES IN ALUMINUM BOXES, always COAT the THREADS with a compound of petrolatum and zinc dust before threading the terminal tube into a snug fit.

21. Always USE COPPER TERMINALS IN making CABLE CONNECTIONS. The terminal should be of such size that the conductor fits snugly into the terminal. Each strand must be cleaned before final connection is made. The insulation must extend to the terminal.

22. When the use of a standard copper terminal is not practicable always form a loop or eye from the clean, bare conductor then dip the whole eye into solder.

23. ALWAYS FIT PLUGS INTO the UNUSED OUTLETS IN WATERTIGHT BOXES. Use brass pipe plugs in brass boxes, steel pipe plugs in aluminum boxes.

Remember that neatness is a large factor in your job. Neatness in your work is just as important as neatness of your personal appearance.

QUIZ

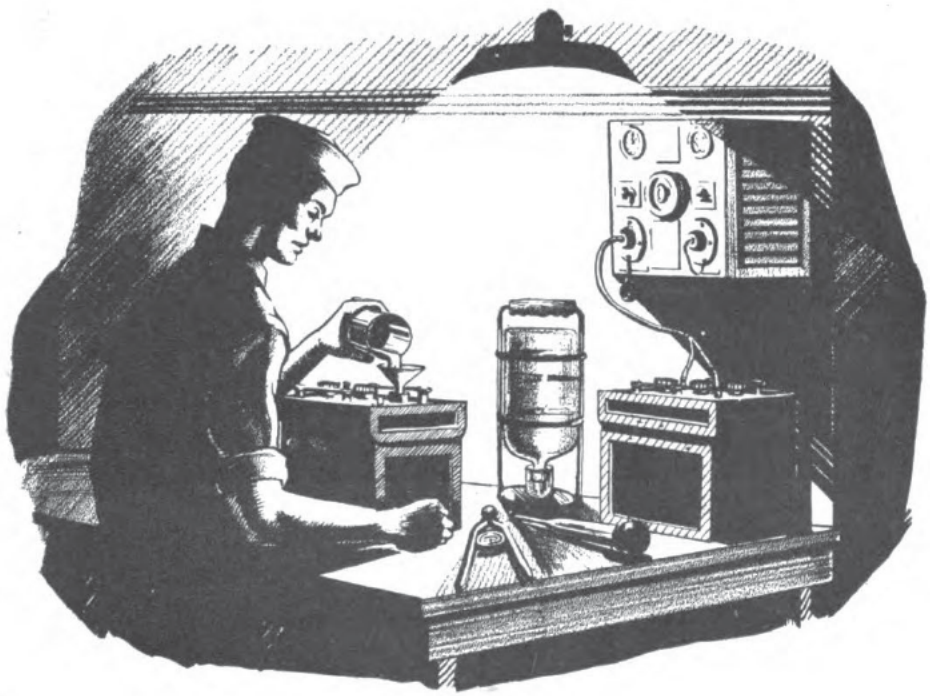
1. Complete the following statements:
   (a) A cable consists of one or more ------ insulated from each other but within a single casing.
   (b) A ------ cable has several conductors insulated from each other.
2. Name the five insulation classifications for Navy cables.
3. Complete the following statements:
   (a) The standard Navy system for identifying cables indicates, by letters and numbers:
      1. ------ of conductors.
      2. ------ of insulation.
      3. ------ of cable covering.
      4. ------ of each conductor.
4. Identify each of the cables listed below as to type of insulation, type of sheath, number of conductors, and approximate size of conductors.

   TCOP—4
   DHFA—14
5. For each of the cable symbols listed below, tell what type of insulation, type of cable sheath, number of conductors and approximate size of conductors the symbol represents.

   TCOP—4
   DHFA—14
   MHFA—44
   FCOP—9
6. Complete the following statements:
   (a) When installing a power circuit, the size wire you pick should not produce a voltage drop greater than ------ percent of the voltage at the nearest generator switchboard.
   (b) To find the size wire necessary to install a power circuit, you have to know these three factors.
      1. The number of ------ the circuit will carry.
      2. The ------ of the circuit.
      3. The ------ voltage drop.
   (c) If you know the three factors indicated in (b), you can find the size of conductor to use in installing a

circuit from the formula: Wire size (area in circular mils) ______.

7. You are to install a circuit to connect a motor to a 230-volt bus bar. The length of wire run from motor to bus bar is 50 feet. The motor draws 20 amperes at full load. What size wire must be used?
8. You have to connect a bank of lamps to a bus bar. The wire run from the bus bar to the lamp bank is 100 feet. The lamp bank will draw 10 amperes. What size wire should be used?
9. Complete the following statements:
   (a) In shipboard wiring installations cable junctions are always made inside ______.
   (b) Cables passing through bulkheads, decks, and into the housings of electrical units go through ______ to obtain water tight integrity.
   (c) Cable connections to branch circuits inside electrical units are made at ______ inside the units.
   (d) Wiring systems inside turrets and mounts are under the cognizance of the Bureau of ______.
   (e) Turret and mount electrical systems are described in instruction manuals called ______.
   (f) Instruction manuals on turret and mount electrical systems can be obtained from your ______ officer.
10. Name the 23 major precautions to be observed in working on shipboard wiring systems.



CHAPTER 13

BATTERIES

ELECTRICITY FROM CHEMICALS

You learned in *Electricity*, NavPers 10622, that a battery is a device for chemically producing an emf. You also learned that each battery is made up of CELLS. First there are the PRIMARY cells, commonly known as DRY cells. When discharged they must be replaced with new cells. The SECONDARY, or STORAGE type cells, when discharged can be recharged by passing direct current through them in the reverse direction.

The typical primary cell has a ZINC case which forms the NEGATIVE terminal and a CARBON center post which forms the POSITIVE terminal. The electrolyte is chemically active paste. When the chemical becomes dry the cell is no longer of any use.

The zinc case sometimes corrodes and the chemical leaks out. The escaped chemicals can damage the equipment around the batteries and render it useless. Therefore, remember, WHEN a piece of equipment using dry cells for

the source of power is NOT IN USE, always REMOVE THE BATTERIES from their holders.

Dry cells are used for radios, for portable lights, and for many types of testing equipment. The cells are connected

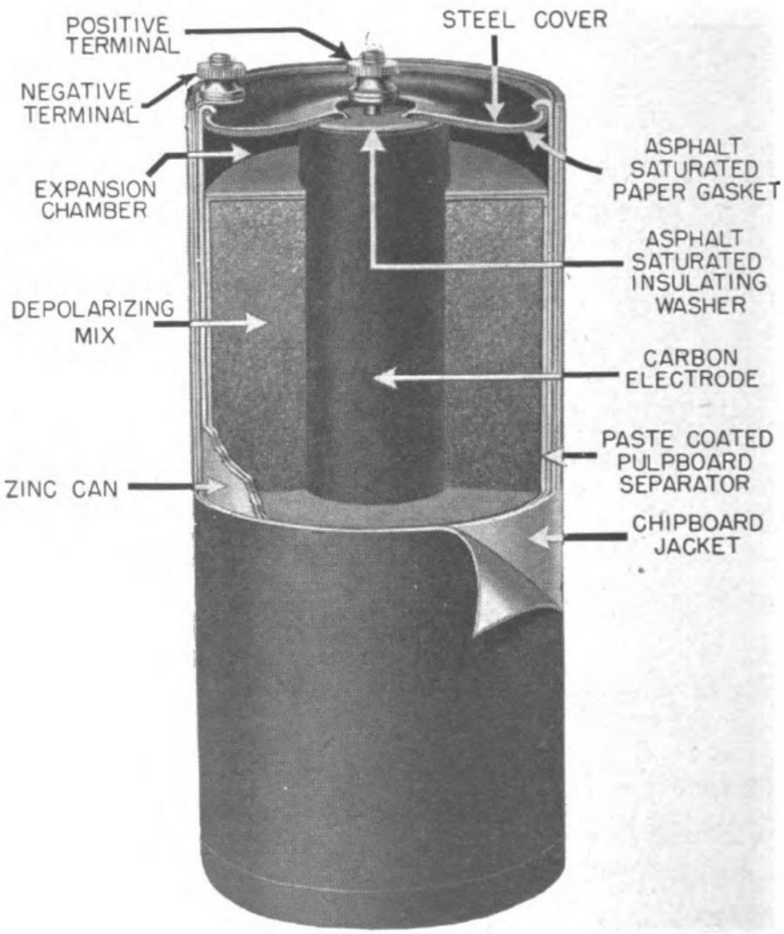


Figure 126.—A dry cell.

together in commercial dry batteries that deliver a range of potentials from 1½ to as high as 500 volts.

EDISON CELL

The battery you will be most concerned with are the storage types and the two most common of these are the EDISON and the LEAD ACID cells.

The Edison cell has nickel plates with potash as the electrolyte. With this cell you cannot determine its condition by testing the electrolyte with a hydrometer; you

must check its condition with a voltmeter. It is impossible to harm the Edison battery by overcharge or by leaving it discharged for long periods of time. Occasionally this cell becomes sluggish and will not deliver its rated current flow. When this happens the cell must be charged fully and then put on a discharge rack and discharged completely. Then when it is recharged it should operate properly. If it does not, repeat the process. The Edison battery, as with all types of storage cells, should have enough electrolyte to cover the plates. The greatest disadvantage of this cell is its high initial cost.

LEAD ACID CELL

The lead acid cell is the most common storage cell. Its negative plates are lead oxide and the positive plates are lead peroxide. The electrolyte is a solution of sulphuric acid.

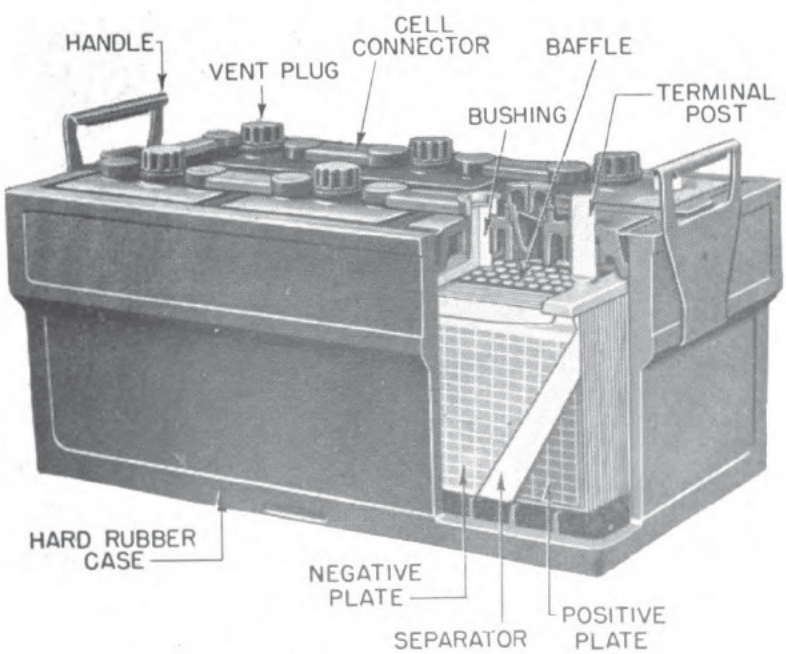


Figure 127.—Lead-acid storage cell.

Each positive or negative set of plates is called a group. When these groups are assembled, separators of wood, rubber, or glass are placed between the unlike plates to act as insulators. These insulators or separators are grooved

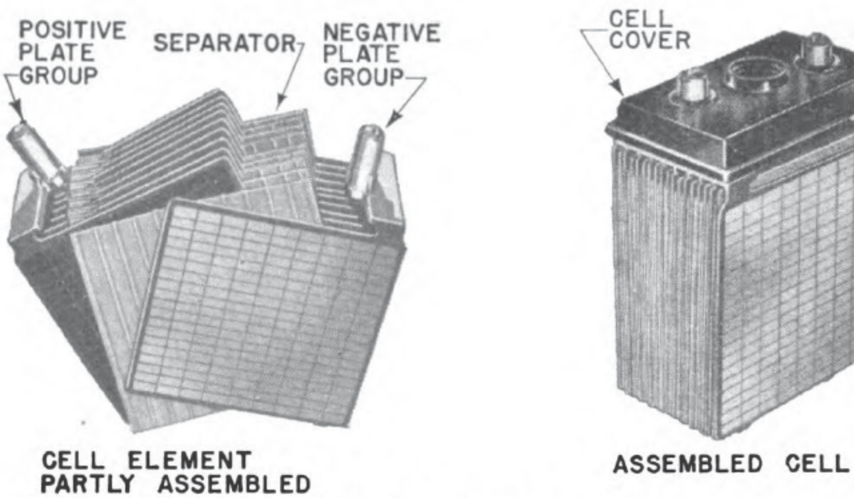


Figure 128.—Lead acid cell plates.

on the side next to the positive plates to permit free circulation of electrolyte as the greatest chemical reaction takes place there. The grooves also permit the sheddings from

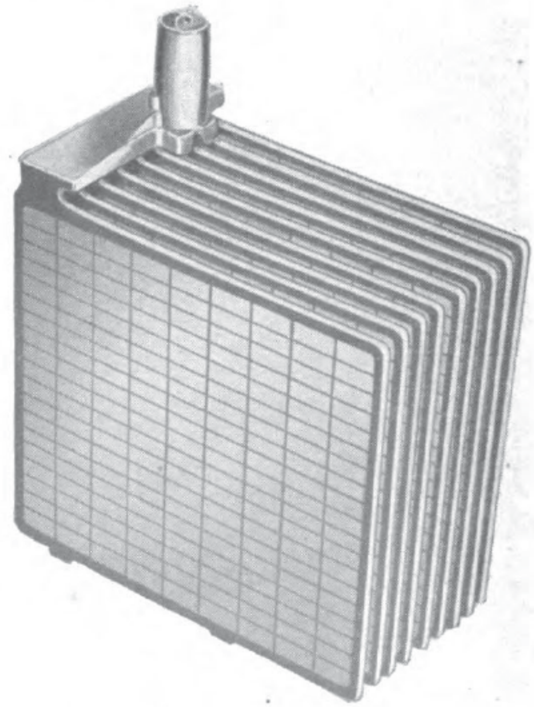


Figure 129.—A plate group.

the plates to fall to the bottom of the case. A sediment chamber for collecting sheddings is present in all cell cases.

A storage cell must have a vent opening to the outside air because the chemical reaction developes heat, causes the

electrolyte to expand, and liberates gasses. Usually this vent opening is provided in the plug screwed into the cell cover. The plug has baffle plates to prevent the acid spray from leaving the cell along with the gasses.

BATTERY RATINGS

Storage batteries are rated by their VOLTAGE and by their AMPERE-HOUR CAPACITY. Each cell has a fixed voltage output—1.2 volts for the Edison cell, 2.0 volts for the lead-acid cell. To get higher voltage ouptut from the battery it has more cells connected in series. Therefore Edison type batteries come in multiples of 1.2 volts, such as 4.8-volt and 7.2-volt ratings; lead-acid batteries come in multiples of 2 volts, such as 4-volt, and 6-volt ratings.

AMPERE-HOUR CAPACITY

The amount of electricity (charge) which can be stored in a storage battery is called the battery's AMPERE-HOUR CAPACITY. If the battery has a 100-ampere-hour capacity, it can discharge: 1 ampere for 100 hours; 2 amperes for 50 hours; or 50 amperes for 2 hours. Thus the ampere-hours capacity tells you how much current can be drawn from the battery for how long, and the formula for ampere-hour capacity is—

Capacity (ampere-hours) = Current (amperes) $\times$ time (hours) that the current flows.

$$C = I \times t$$

The voltage rating and ampere-hour rating of a battery are stamped on the battery name plate. Knowing these ratings, you can solve the problems which usually come up in connection with batteries. As an illustration, consider this example:

The emergency light at the powder hoist loading station of a certain 5-inch mount is a 6-volt, 24-watt lamp. This lamp is fed from a storage battery rated 6 volts and 100 ampere-hours capacity. How long can the battery keep this emergency lamp lighted?

You learned in chapter 1 that the power used up in a resistance is—

$$P = E \times I$$

For the lamp, P=24 watts, E=6 volts. So the battery current, I, to keep the lamp lighted is—

$$24=6\times I$$

$$\frac{24}{6}=I$$

$$1=4 \text{ amperes}$$

The formula for ampere-hours capacity tells you that—

$$\text{Capacity}=\text{Current}\times\text{Number of hours.}$$

Since the battery has a capacity of 100 ampere-hours, and the current drawn is 4 amperes,

$$100=4\times\text{Number of hours.}$$

$$\frac{100}{4}=\text{Number of hours}$$

$$25=\text{Number of hours}$$

Thus the 100-ampere-hour battery will keep the lamp lighted (by providing a current of 4 amperes) for 25 hours.

Ampere-hour capacity depends on the area of active plate material. Therefore, the larger the battery plates, and the more of them, the greater its ampere-hour capacity. You can also provide more ampere-hour capacity by tying batteries together in parallel.

LEAD ACID CELL ACTION.

The positive plate of a battery is lead peroxide (PbO_2), chocolate brown in color, and the negative plate is spongy lead, gray in color. When the battery deliveries electricity to a load and is being discharged, the chemical action between the sulphuric acid and the plates deposits lead sulphate on both plates and replaces the acid with water. When the cell is being charged, it receives electricity from a generator and electricity is passed through the cell in the reverse direction. The reverse chemical reaction takes place and the sulphuric acid replaces the water in the electrolyte. When the cell is fully discharged there is not enough sulphuric acid left in the electrolyte for a chemical reaction.

BATTERY TESTING—THE DEGREE OF CHARGE

The degree of charge of a storage battery can be determined by the specific gravity of the electrolyte since the percentage of acid varies directly with the state of battery charge. The electrolyte contains 39.2 percent sulphuric acid and 60.8 percent water when the battery is fully charged. The specific gravity of sulphuric acid is 1.835 and of water is 1.000. Hence the hydrometer reading for the electrolyte at full charge is, in this case, 1.300.

In testing batteries you must also take into consideration the temperature of the electrolyte because at higher temperatures the material is more active. Using 80° F. as the mean temperature, for each 3° increase in temperature add 0.001 to the specific gravity. As an example, if you get a reading of 1.190 at 86° F., add 0.002 to the reading, making the specific gravity 1.192.

BATTERIES operating IN ARCTIC CLIMATES MUST have a specific gravity of about 1.300 at full charge and must NOT BE FULLY DISCHARGED because the electrolyte of a discharged battery is mostly water and will freeze. In other climates a fully charged standard Navy battery should read about 1.210 to 1.220 and 1.060 when fully discharged.

BATTERY CHARGING

Battery terminal voltage varies considerably depending on whether the battery is being charged or discharged, the rate of charge or discharge, the temperature, and the specific gravity. All these points must be taken into consideration since the rate of charging depends on the terminal voltage of the generator used in recharging it. Special generators for battery charging are provided aboard ship. These should be operated in accordance with the battery-charging PRECAUTIONS given in a later paragraph.

SELF DISCHARGE

Discharge takes place in batteries even when not in use. The rate of discharge varies with temperature and specific gravity of the electrolyte. Figure 130 shows a discharge

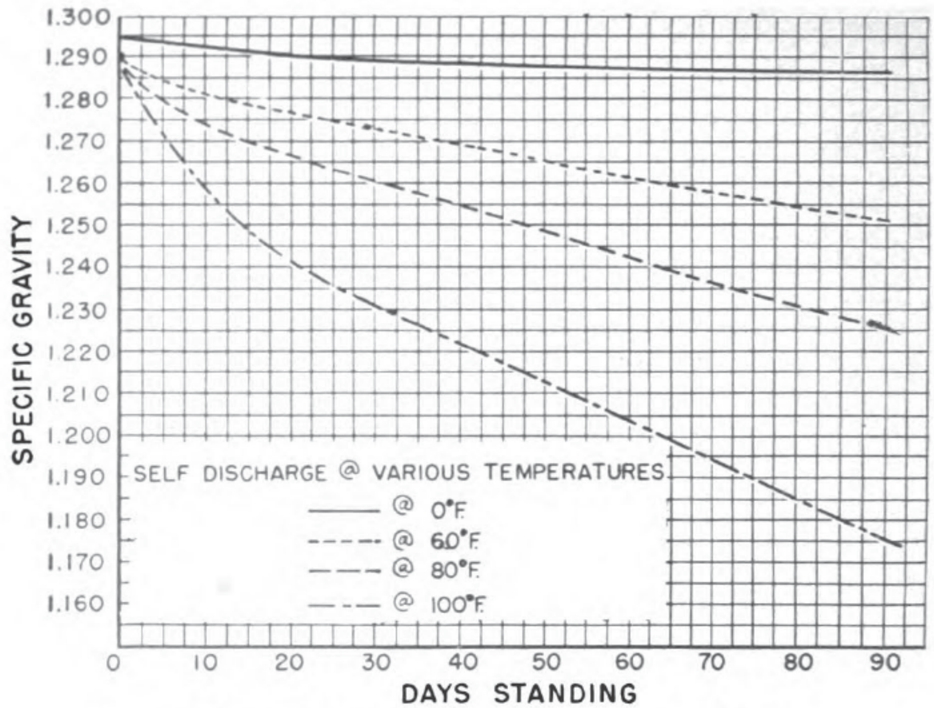


Figure 130.—Self-discharge curve for lead-acid battery.

rate chart. Self-discharge changes the specific gravity of the electrolyte, just as normal discharge does. Therefore a battery must be checked even though it is not in use, or remains in storage, to prevent freezing of electrolyte. At 1.100 gravity the electrolyte freezes at 18° F., at 1.220 it freezes at —31° F., and at 1.300 it freezes at —95° F.

CARE OF BATTERIES

When in operation, batteries must be kept clean and free from salt water and corrosion and in cool locations. They must be kept away from open flames. Each battery should be checked at least once a week with a hydrometer and a record kept of its condition.

When the cells in a battery read quite differently in specific gravity, they should be checked to determine the cause of the condition. There may be short circuits in the cells, or cells may have loss of acid resulting from a cracked case or by spraying out through the vent opening. High readings may indicate excessive water evaporation.

Care must be taken NOT TO OVERCHARGE the battery as this will cause the plates to buckle and crumble. Overcharge

can be noted by the requirement of an excessive amount of water. The ELECTROLYTE MUST NEVER be allowed to FALL BELOW the TOP OF the PLATES.

If a battery is left discharged for a long time the plates will become sulphated and inactive.

Battery holders should also be kept tight, clean and well painted to prevent battery from falling out of place, rusting or corroding.

Bulged cases are caused either by excessive temperatures or clamps being drawn down too tight.

INSTALLING NEW BATTERIES

Many new batteries delivered to the Navy were shipped without electrolyte and with dry plates charged. Care must be taken to keep these batteries sealed until ready for use. To put one of these in use open sealed vent plugs and fill each cell with electrolyte to about one-half inch above plates. Let stand for about two hours and fill to the same level again. This battery can be used immediately but it is much better to discharge it and place on a 6-ampere charge for about 24 hours or until the battery is fully charged.

BATTERY CHARGING PRECAUTIONS

Never charge a 100-ampere-hour battery at a rate over 15 to 18 amperes, and the impressed voltage across the battery should only be about 20 percent higher than the voltage of the cell itself. BE very CAREFUL THAT the BATTERY NEVER GETS TO OVER 125° F IN CHARGING as it will buckle the plates. Be very careful to NEVER HAVE OPEN FLAMES NEAR a BATTERY CHARGING ROOM since hydrogen gas is given off during the charging, and the hydrogen gas mixed with the oxygen in the air makes a highly explosive atmosphere.

MIXING ELECTROLYTE

You will have to know how to mix the electrolyte and this must be done very carefully. Use a STONE, GLASS, RUBBER, or lead VESSEL, NEVER A METAL ONE. Put the necessary amount of water into the vessel and then slowly pour ACID INTO the WATER, NEVER POUR WATER INTO ACID

BECAUSE an EXPLOSION WILL RESULT. While pouring, stir solution of electrolyte with wooden paddle. Allow the mixture to cool, then take a hydrometer reading and correct it to 80° F as explained under BATTERY TESTING—DEGREE OF CHARGE. Never let the temperature get below 60° F. By all means BE CAREFUL NOT TO SPILL, as a solution of sulphuric ACID WILL BURN THE SKIN badly AND DAMAGE almost ANYTHING it is SPILLED UPON.

Electrolyte and water suspected of having harmful impurities should be sent to Naval Shipyard chemists for test. Allowable amounts of impurities are listed in BuShips Manual, Chapter 62, which gives detailed instructions on all phases of battery care and repair.

As a reminder, batteries operate on an electrochemical reaction using strong chemicals as electrolytes, so TAKE great CARE TO PREVENT SPILLING and damaging equipment. Always KEEP CONNECTIONS CLEAN AND TIGHT TO PREVENT arcing that may cause an EXPLOSION. NEVER LET THE BATTERY TEMPERATURE GET ABOVE 110° F.

QUIZ

1. What is the basic difference between primary and secondary cells?
2. Complete the following statements:
   (a) In a dry cell
      1. The zinc case forms the ______ terminal.
      2. The carbon center post is the ______ terminal.
   (b) Because the zinc casing of dry cells may become eaten away, when equipment using dry cells is not in use the batteries should be ______.
   (c) In the Edison type storage cell, you test condition of the electrolyte with a ______.
   (d) In the lead-acid storage cell you check electrolyte condition with a ______.
   (e) The electrolyte in the lead-acid storage cell is ______.
3. Why must a lead-acid cell have a vent opening to the outside air?
4. How is acid spray through the vent of a storage cell prevented?

5. Complete the following statements:
   (a) Each lead-acid cell produces a fixed voltage output of ------ volts.
   (b) The ability of a storage battery to store electricity is called its ------ capacity.
   (c) The formula for this capacity is:
   Capacity (ampere-hours) = ------ × ------.
6. The 5 lights on a small craft are connected in parallel and fed by a 6-volt, 100-ampere hour battery. Each light is a 24-watt lamp. How long could this battery keep these lamps lighted?
7. The emergency lighting circuit of a 5-inch mount consists of 5 24-watt lamps in parallel. If this circuit is fed by a 6-volt battery, what ampere hour capacity should this battery have to be able to keep the circuit lighted for 2½ hours?
8. Complete the following statements:
   (a) When a lead acid battery is being discharged, the chemical action
      1. Deposits ------ on the plates.
      2. Replaces the acid with ------.
   (b) When a lead acid cell is fully discharged there is not enough ------ left in the electrolyte for a chemical reaction.
   (c) The degree of charge of a lead-acid cell can be determined by the ------ of the electrolyte.
   (d) The hydrameter reading for a lead acid cell at full charge is ------.
   (e) For each 3° temperature increase above 80° F ------ should be added to the specific gravity reading in (d).
   (f) Batteries in Arctic climates should not be fully discharged because of danger that the electrolyte will ------.
   (g) In tropic climates a fully charged Navy battery should have hydrometer readings of.
      1. ------ to ------ when fully charged.
      2. ------ when fully discharged.
9. Complete the following statements:
   (a) A storage battery not in use must be checked for

specific gravity, because its specific gravity changes due to ______.

(b) When cells in a storage battery read quite differently, it is due to:

1. ______ in the cells.
2. loss of ______ in the cells.

(c) Overcharge of batteries will cause the plates to ______.

(d) The electrolyte in a cell must always be kept above the ______.

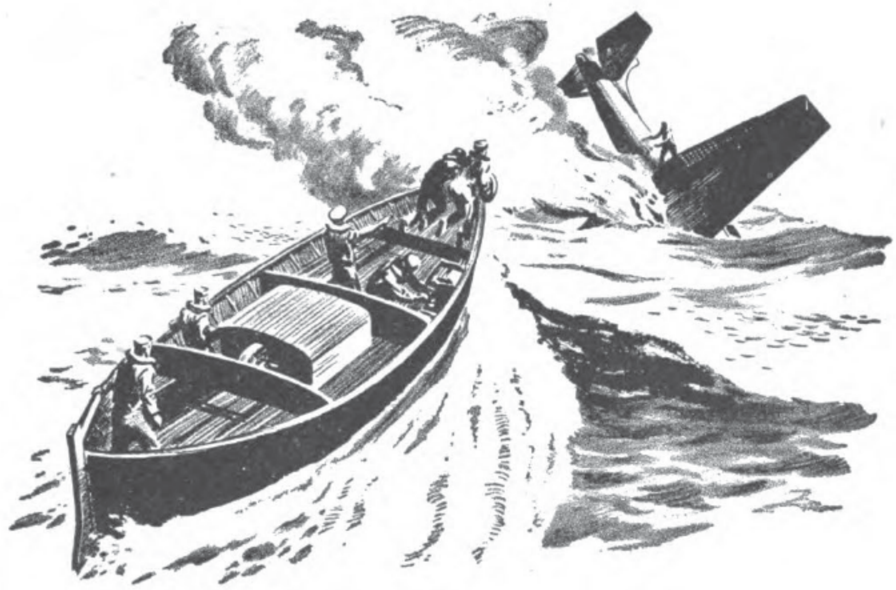
(e) To install new battery,

1. Open ______.
2. Fill each cell with ______.
3. Refill after ______ hours.

10. Why must open flames be kept away from battery charging rooms?
11. Why must batteries not be allowed to get hotter than 125° F during charging?
12. Complete the following statement:

(a) When mixing electrolyte, use stone, glass or rubber vessel, never one of ______.

13. Why must acid always be poured into water when mixing electrolyte?
14. Why must any spilling be avoided when mixing electrolyte?
15. How would you test if electrolyte has foreign chemicals that make it unfit for battery use?



CHAPTER 14

ELECTRICAL SYSTEMS IN SMALL CRAFT

YOU TEND THE ELECTRICITY

Small craft are an important part of a ship's equipment because they are used for liberty boats, for ferrying service personnel between ship and shore where the ships are not able to dock, and for a dozen other similar duties. Your interest in the ship's boats is more than whether you will make the last liberty boat, for it is your duty, as Electrician's Mate, to keep the boat's motor starter, its ignition system and its lights going.

The heart of a small craft electrical installation is its battery. It would be impossible to do without one because diesel engines must have an electric motor to turn the engine over in starting; gasoline engine driven boats have electrical ignition systems in addition to the starting motor; and all small craft must have running lights, which are operated by battery current.

SMALL CRAFT BATTERIES

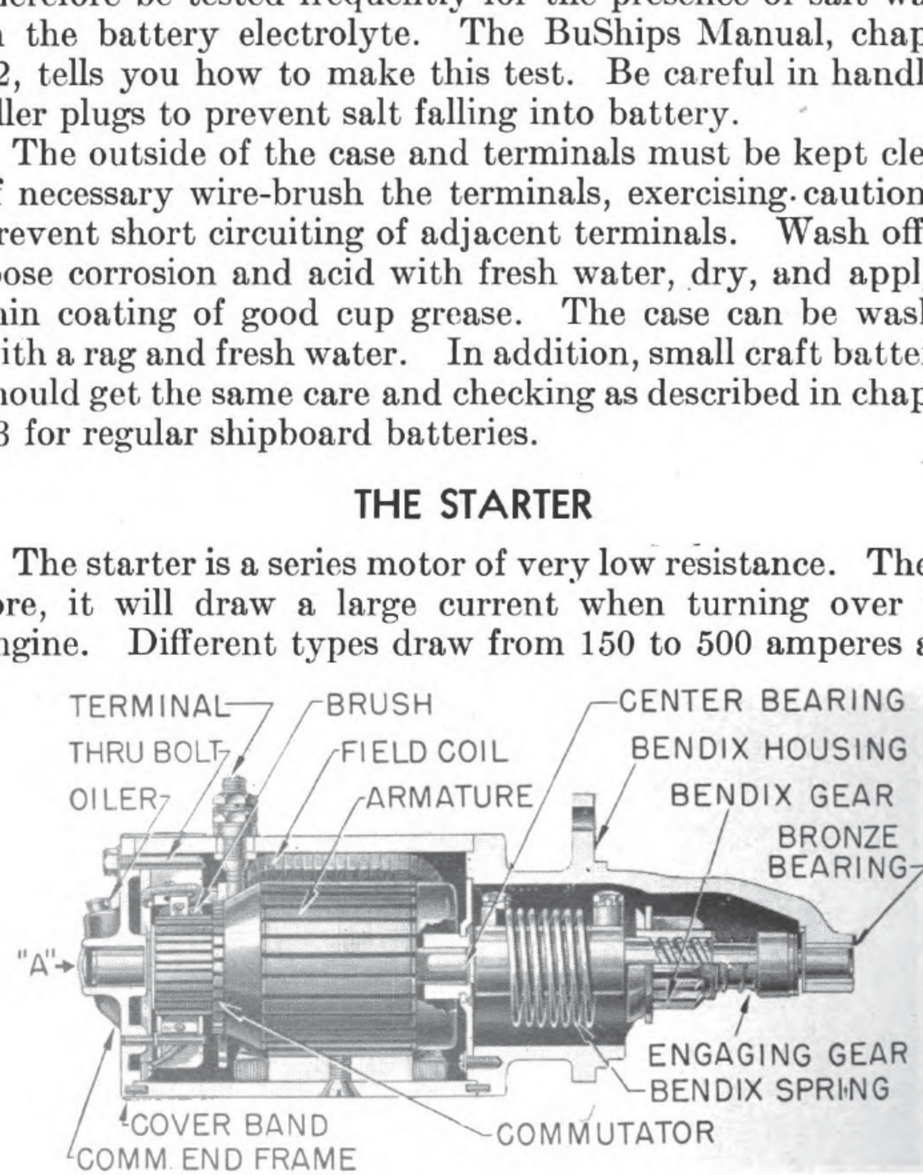
First, the battery must be located close to the starting motor, so it will not have a large voltage loss in the cable run between battery and starter.

You must protect the battery from salt water or the terminals will corrode. If the electrolyte becomes mixed with salt water, chemical reaction occurs which will ruin the plates. In addition salt water and sulphuric acid, if mixed, will give off poisonous chlorine fumes. Small craft batteries must therefore be tested frequently for the presence of salt water in the battery electrolyte. The BuShips Manual, chapter 62, tells you how to make this test. Be careful in handling filler plugs to prevent salt falling into battery.

The outside of the case and terminals must be kept clean. If necessary wire-brush the terminals, exercising caution to prevent short circuiting of adjacent terminals. Wash off all loose corrosion and acid with fresh water, dry, and apply a thin coating of good cup grease. The case can be washed with a rag and fresh water. In addition, small craft batteries should get the same care and checking as described in chapter 13 for regular shipboard batteries.

THE STARTER

The starter is a series motor of very low resistance. Therefore, it will draw a large current when turning over the engine. Different types draw from 150 to 500 amperes and



NOTE: ROTATION COUNTER-CLOCKWISE WHEN LOOKING AS AT "A"

Figure 131.—Starter engaging mechanism, centrifugal type.

will rapidly discharge a battery. So if the starter is cranking, and the engine fails to start in a short period, check the engine for trouble. Such heavy currents not only rapidly discharge the battery, but if kept up for long produce harm-

ful chemical changes in the battery. A STARTER SHOULD therefore NEVER BE KEPT RUNNING OVER 20 SECONDS at a time, and intervals of at least a minute should be allowed between attempts to start the engine.

Most starters are either four-pole or six-pole machines requiring potentials from 6 to 32 volts depending upon the size and the types of engine. Due to the heavy currents they carry, starters are wound with heavy copper wire both in the fields and armature. Two or three brushes sometimes are necessary to carry the current. They are placed side by side so they feed the current to the same commutator segment.

The 6- and 12-volt starters complete their circuits by grounding through their frame or housing while starters of higher voltage have a plus and minus terminal and are insulated completely from the housing.

STARTER CARE

Starters require the same care,.maintenance, and trouble correction given in chapter 10 for all types of d-c motors. In addition, they require particular care as follows:

> Salt water is the enemy of starters. Hence starter COVERS AND GASKETS SHOULD BE SECURED AT ALL TIMES. TERMINALS AND LEADS on starters MUST BE CLEAN AND SECURE to prevent arcing. Arcing by the heavy currents which flows through starters will rapidly burn away even the heaviest conductors and terminals.

STARTER ENGAGING MECHANISMS

Engaging mechanisms of starters vary; some have Bendix centrifugal engagements like the one shown in figure 131, while others use an electric solenoid connected to the engaging yoke as shown in figure 132.

The solenoid relay in figure 132 is a relay switch so the heavy starter current does not have to travel all the way from the battery, through the starter button, to the starter and back to the battery again. On other starters, the solenoid attracts a plunger attached to the Bendix engaging arm as illustrated in figure 133.

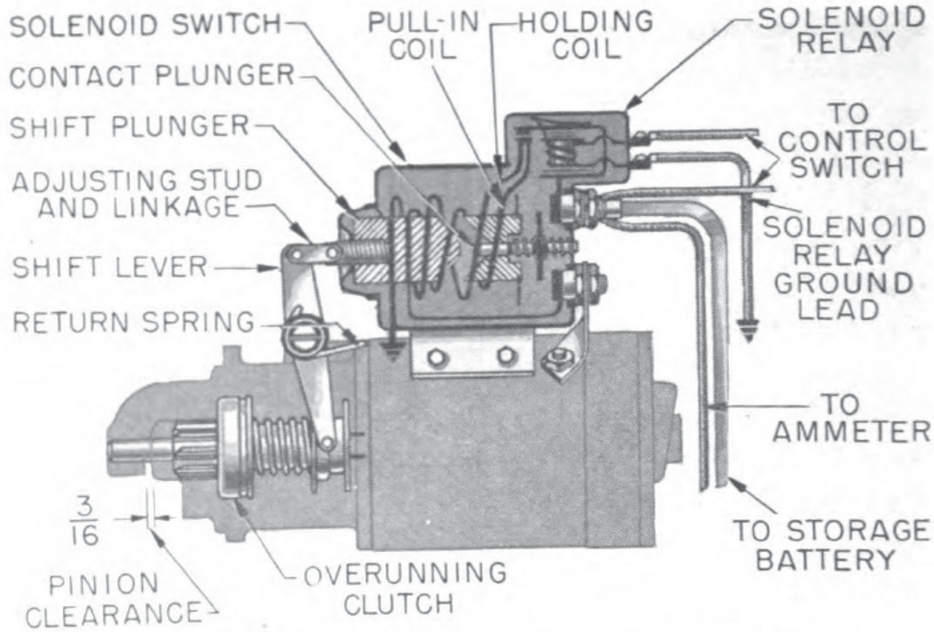


Figure 132.—Starter engaging mechanism, solenoid type.

STARTER MAINTENANCE

The BRUSHES must be checked at each monthly inspection to detect wear and loose connections. Be sure to see that they are not stuck in brushholders.

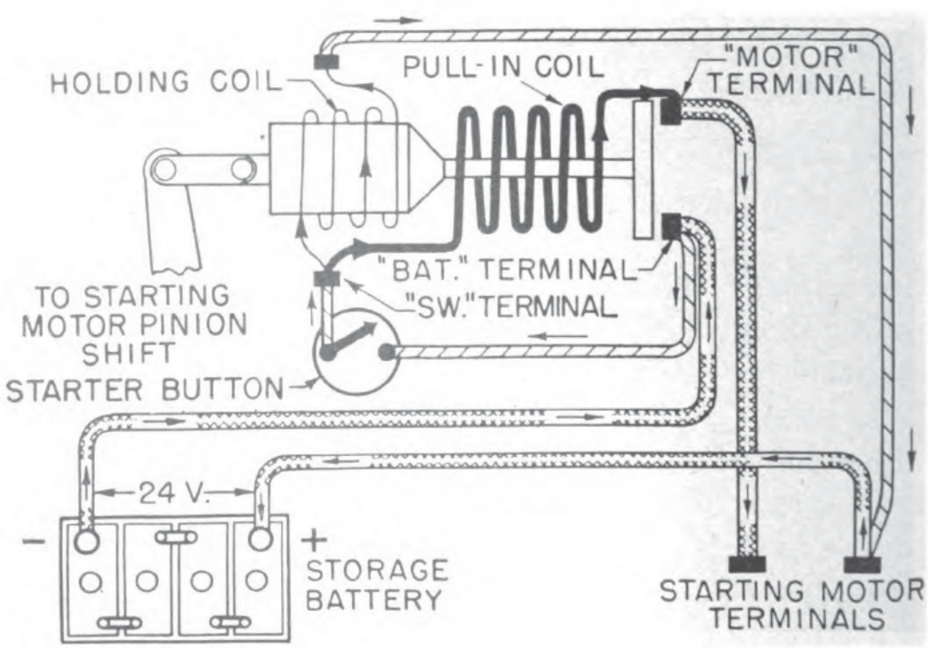


Figure 133.—Circuit diagram, solenoid engaging mechanism.

The COMMUTATOR should be of light bronze color. Deeper red color shows there has been overheating. Check frequently for commutator shorts or brush trouble.

Starter BEARINGS usually are of the sleeve bushing type and should be checked for wear. Bearings should be oiled once a month but take care not to over-oil as the oil may be thrown onto the armature and commutator causing other troubles.

The Gray Marine Diesel engines, used in landing craft, have a 12-volt electrical system. The starter in these installations is worked at maximum capacity and if a slight drag on the engine is present the starter will not turn over. The water pump has been found to be the cause of the greatest engine drag.

The solenoids are not repairable as they are sealed units, but the contact post and disc can be removed, cleaned, sanded or replaced as necessary. If they are replaced, the plunger must be adjusted so the electrical contact will be made at the proper time in relationship to engaging of the Bendix gear.

For other common starter troubles and how to spot and correct them, see the TROUBLE CHART of Chapter 10.

THE GENERATOR

The generator supplies the charging current to the battery. The generators are shunt wound and have two or four brushes, depending on the number of poles. The two-brush type often has a third brush for current regulation, connected as shown in figure 134. The field is thus connected between the third brush and the brush next to it.

This third brush is adjustable so it can be moved toward or away from the brush connected to the other field lead. Moving it toward that brush decreases the voltage across the field and thus decreases the generator's voltage output; and moving it away increases the voltage output. The constant voltage output of this generator over a wide range of speeds is its chief advantage.

This type generator has a cutout or reverse relay in series with the load so the generator will not draw current from

the battery and act as a motor when the engine is not operating.

The fixed brush (shunt) type generator of figure 134 has one field lead connected to one brush and the other connected

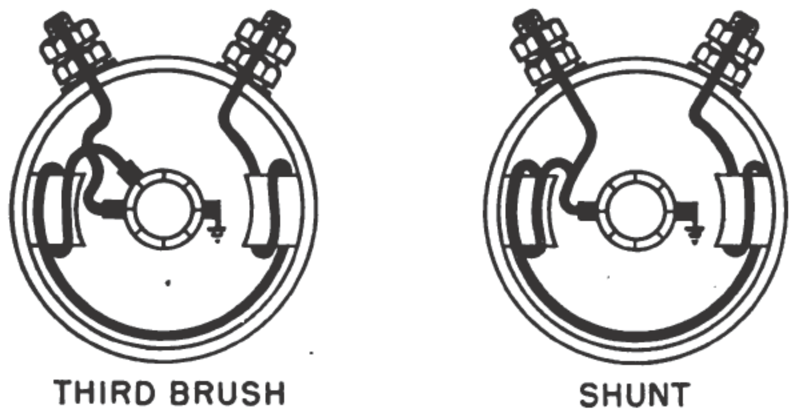


Figure 134.—Generator windings.

to an external binding post. From this post the other lead goes through the regulator and battery to ground, as shown in figure 135.

VOLTAGE REGULATORS

Voltage regulators are of many types, and the circuits vary greatly according to the manufacturer's design. All regulators are designed to prevent overcharging both in voltage and charging rate. In all types the regulator is a relay which automatically cuts in or cuts out resistance in the circuit so as to keep the current or voltage constant.

The regulator in figure 135 with its simplified schematic diagram is representative of a type used with a two-brush generator, while the diagram in figure 136 is for a generator using the third brush.

These regulators are fully automatic when properly adjusted and will vary the current necessary to keep the battery charged. If the battery is charged the regulator will allow just a small trickle of current to flow into the battery but when the battery begins to drop in voltage it will charge it to the maximum potential with a current between 16–18 amperes for 12-volt system; while on the 32-volt system the current is between 6–8 amperes.

Voltage adjustments are made while the generator is

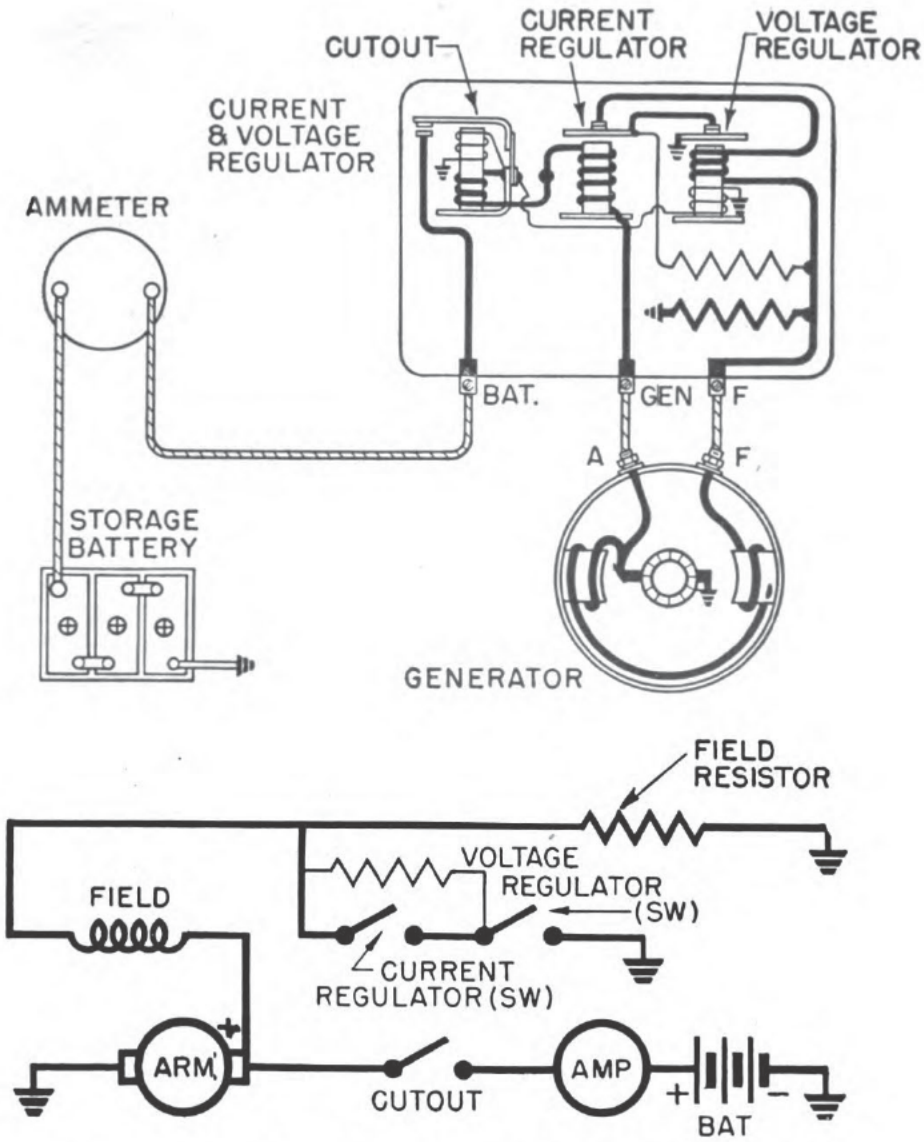


Figure 135.—Voltage regulator for a two-brush generator.

running on an open circuit. It should be set so the voltage output is about 16% higher than the standard battery voltage. For instance, on 12-volt battery the voltage output should be about 14.2 volts. After voltage adjustment, connect the generator to load and adjust current regulator to the desired current level, MAKING SURE the CHOSEN CURRENT IS LESS THAN the GENERATOR'S OUTPUT. If you set it above maximum current output you probably will burn out the generator. Figure 137 is typical of many voltage and current regulators installed with the generators in many Navy boats.

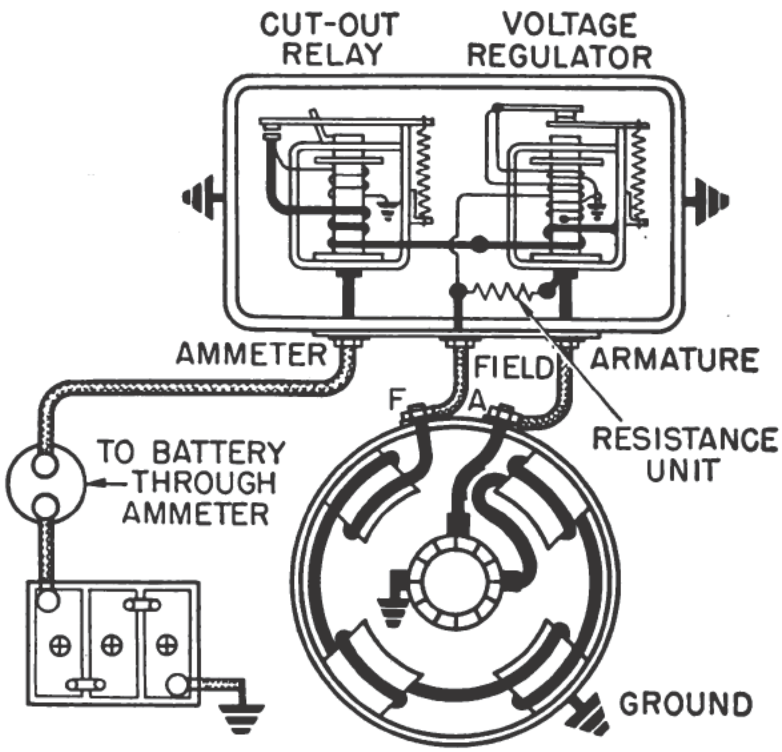
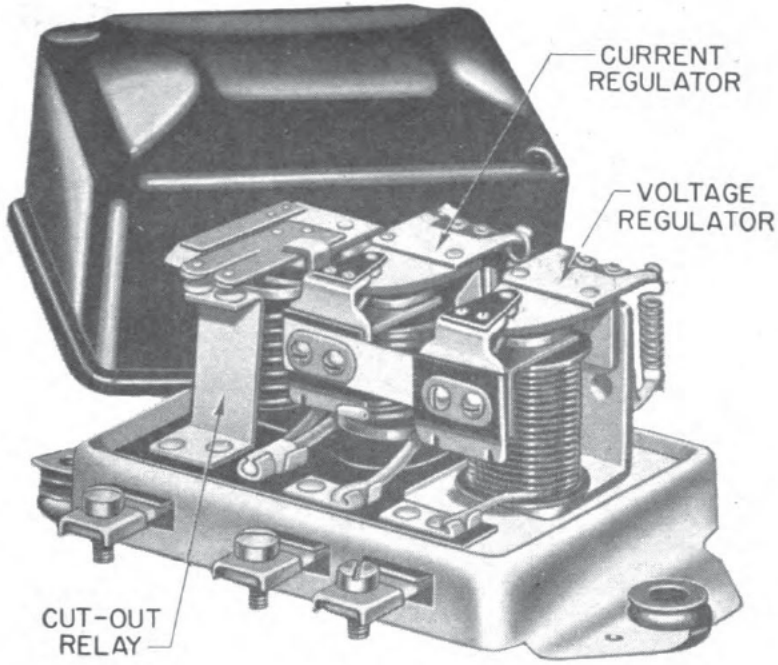


Figure 136.—Voltage regulator for a three-brush generator.

IGNITION SYSTEMS

The ignition systems in figure 138 is for a gasoline engine and, as you know, is used to explode gaseous mixture in the cylinders by causing an electrical spark to jump across a gap in a spark plug. Before you can have a spark you must have something to produce high voltage since battery voltages seldom are over 24 volts. The high voltages are produced by breaking the battery current into pulses of d-c which are stepped up by an INDUCTION COIL, and distributed to the right spark plug by the DISTRIBUTOR. This distributor has a set of breaker points, which interrupt the direct current from the battery, making it a pulsating d-c.

The induction coil acts as the transformer and steps up the d-c voltage pulses to about 7,000–12,000 volts. A condenser is placed across the breaker points to prevent pitting of points and absorb the surge of current at the instant the breaker points open.



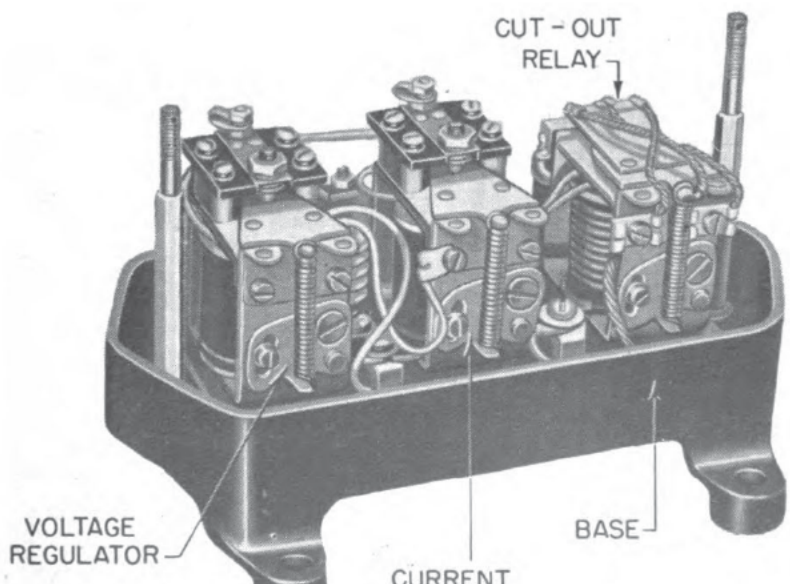


Figure 137.—Voltage regulators.

The high voltage from the coil is carried to the distributor, figure 139, which in turn sends the current to the spark plug of each cylinder just at the right time to produce an explosion in the cylinder. All distributor leads are high voltage and

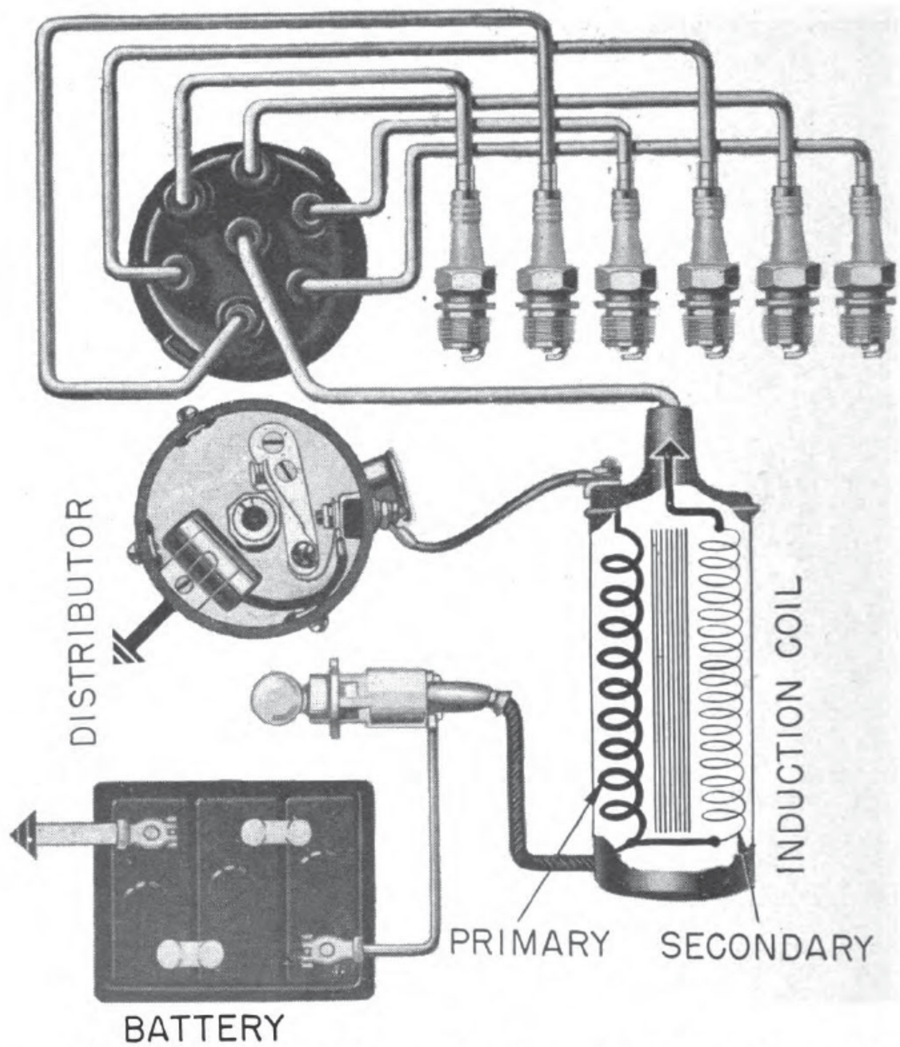


Figure 138.—An ignition system for small craft gasoline engine.

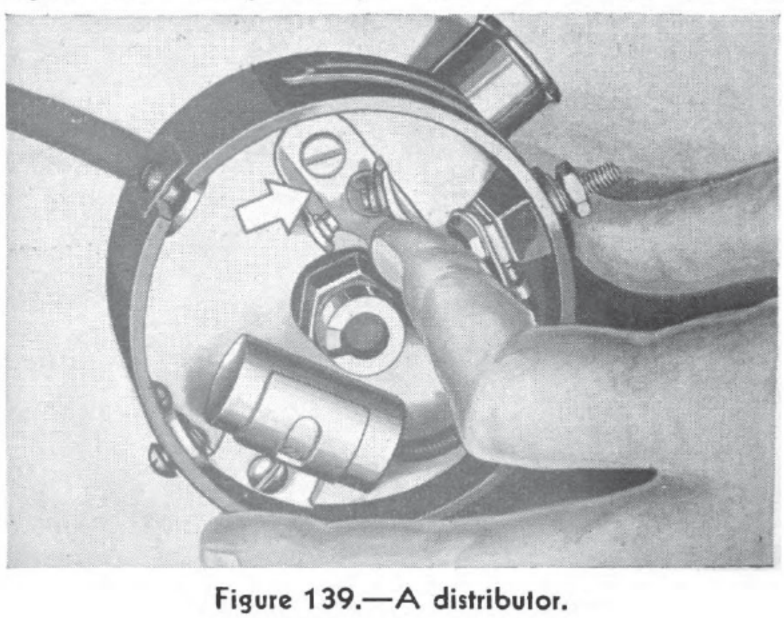


Figure 139.—A distributor.

insulation must be checked from time to time to see that no leakage is present.

THE DISTRIBUTOR

The distributor has three separate operations to perform. First, to break the primary circuit so the direct current can be stepped up; the second is to direct the high voltage to the proper plug at just the right time; then it must have an advancing mechanism so it can advance the firing of the plug

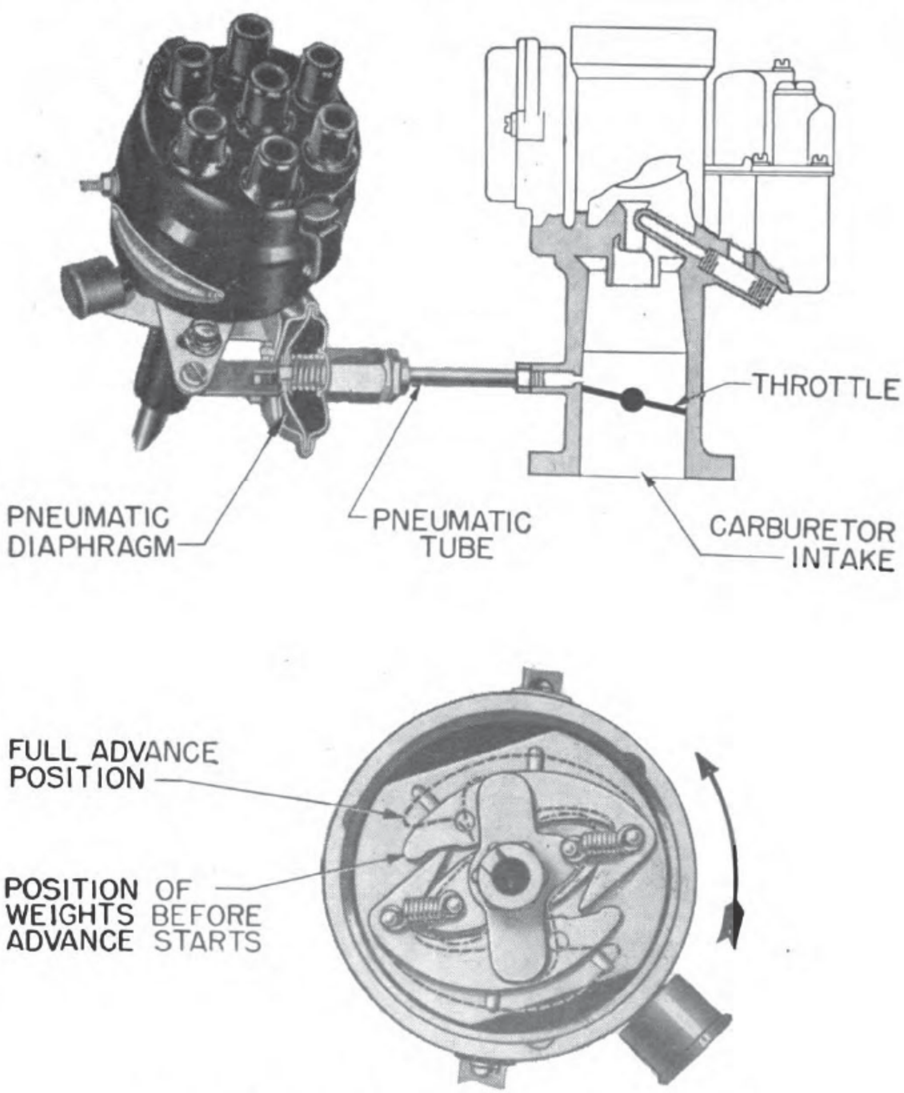


Figure 140.—Distributor advancing mechanism.

as the engine's speed is increased. The advancing mechanism may be a centrifugal device or may operate from a vacuum as illustrated in figure 140.

SPARK PLUGS

Spark plugs are cleaned and cared for by the Motor Machinist's Mates so it is only necessary for you to check the porcelain insulators for cracks and leakage of current.

Diesel engines do not have electrical ignition systems, but they do have HEATERS to heat the fuel oil as it passes into the cylinders. Most diesels have the heater in the form of a GLOW PLUG. It is a high resistance wire inside the cylinder, which wire is heated to a red glow when the heater button is depressed. The Gray Marine engine has a heater plug which actually is a spark plug with a half inch spark. These glow plugs are flame primers used only in cool or cold weather to aid in starting by warming up the air mixture before it reaches the cylinder.

BLOWERS AND LIGHTING

Blowers and necessary lights usually are fed from a distribution panel near the wheel so they can be controlled easily while the boat is in operation. The distribution and switch panels must be water-tight as they are exposed to the weather at all times. The panel wiring is of Navy specification cable and will withstand weather as long as it is well painted and kept free of oil and grease.

Switches must be checked to see they are free from moisture and that the water-tight packing around the shafts of the switch handles is proper.

Fans and blowers should be used only when necessary because they draw large amounts of current. BLOWERS WHICH EXPEL AIR FROM THE ENGINE HOUSING MUST BE USED FOR AT LEAST TEN MINUTES BEFORE STARTING THE ENGINE, TO EXPEL ALL FUMES THAT MIGHT BE IGNITED.

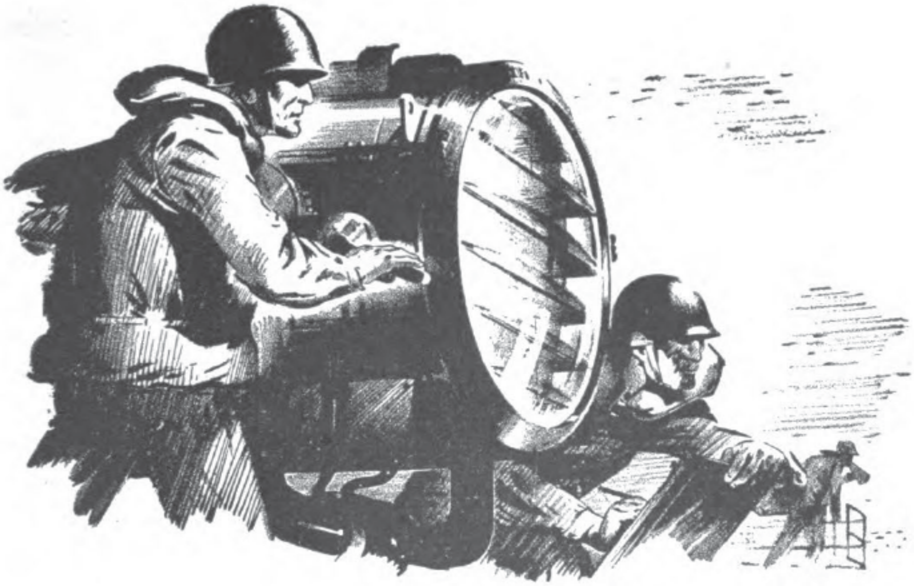
Boats should be checked from time to time to see that all lights are operating properly. The cables should be checked for grounds. Fuses should be replaced only with others of the proper size.

QUIZ

1. Why should special precautions be taken on small craft to keep salt water from getting into the battery electrolyte?
2. How would you test for presence of salt water in a battery electrolyte?
3. Why should the starter for a small boat engine not be run for more than 20 seconds at a time?
4. Complete the following statements:
   (a) The starters for small boat engines are ______ type electric motors.
   (b) 6-volt and 12-volt starters complete their circuits by ______ through the frame or housing.
   (c) Starters of higher than 12 volts are ______ from the frame.
   (d) The principal source of trouble in starters comes from exposure to ______.
5. Why is a starter relay used?
6. Complete the following statements:
   (a) Battery charging generators for small craft have a ______ field.
   (b) Three-brush generators have the ______ connected between the third brush and the brush next to it.
   (c) In three-brush generators the third brush can be shifted to vary the generator's ______ output.
7. What is the purpose of a cutout or reverse current relay in small craft electrical systems?
8. Complete the following statements:
   (a) Voltage regulators are used in small craft electrical systems to prevent ______ of the battery.
   (b) The voltage regulators automatically cut in or cut out ______ in the battery charging circuit.
   (c) Voltage regulators are adjusted to produce a voltage output ______ percent higher than the standard battery voltage.
9. Complete the following statements:
   (a) In a small craft engine ignition system.
      1. Discharge across the ______ explodes the gaseous mixture in the cylinders.

2. The battery current is broken up into pulses by the ______ breaker points.
3. Battery current pulses are stepped up to high voltage by the ______.
4. The discharge voltage is supplied to each cylinder at the right time by the ______.
5. Spark advance as the engine speeds up is automatically produced by the ______.

10. Why is a glow plug used in Diesel engines?
11. How long must blowers which exhaust engine room of small boats be left on before starting engine?



CHAPTER 15

SEARCHLIGHTS

NAVY TYPES

Navy searchlights are classified as to the size and source of light. The 36-inch and 24-inch searchlights use high intensity carbon arcs as the source of light, while the 12-inch searchlights use an incandescent lamp, usually a 1,000-watt lamp. The size of these searchlights is determined by the diameter of the parabolic reflector.

USES OF SEARCHLIGHTS

The 36-inch light is used primarily for fire control. Usually they are equipped with remote control systems so they can be trained and elevated from the gun fire control director. Most are equipped with an iris shutter and may be operated either manually or by an automatic motor.

The 24-inch searchlight is a general purpose light and although it may be used for fire control purposes, generally it is used for long range signaling. These searchlights are not equipped with remote control for train and elevation. The light sometimes is equipped with the remote control signal key. This lamp usually has both the iris and vane type shutter.

The 12-inch searchlight is used primarily for short range signaling. These lights are not equipped with remote control equipment, and have a manually controlled vane type shutter.

REQUIREMENTS OF A SEARCHLIGHT

A Navy searchlight must have a narrow, pencil-like light beam. The light must be nonflickering and of a bluish white color. It must operate properly from any position, under all weather conditions, and give trouble-free operation over a long period of time. The train and elevation characteristics of most lights are: train through 360°, elevation of 110° to 120°, and depression of 30° to 40°.

THEORY OF CARBON ARC SEARCHLIGHT

When an electric current at a moderate voltage is passed through two carbon rods, considerable heat is developed at the point of contact. Now if the carbon rods are separated a short distance a flaming arc will be drawn out.

The act of making contact between the two carbons is necessary to start the arc and is called STRIKING THE ARC. When contact first occurs, a high current flows through the carbons. The high current produces heat which vaporizes the soft center of the positive carbon. This vapor acts as a conductor for the current as the carbons are drawn apart and will keep the current flowing until the distance between the carbons becomes too great. As the distance between the carbons increases the resistance of the arc circuit increases.

The carbon vapor concentrates as a small ball in a depression in the positive carbon. This depression is called the CRATER. This ball of flaming gas in the crater is intensely luminous and is located at the focus of the reflector. The reflector thus projects the light from the arc crater into a beam of light, just as the reflector in your automobile projects the light from the lamp filament into a light beam.

HIGH INTENSITY arcs work on the same principle as low intensity types except that the current is increased and the diameter of the carbon decreased, to obtain a more brilliant and concentrated source of light.

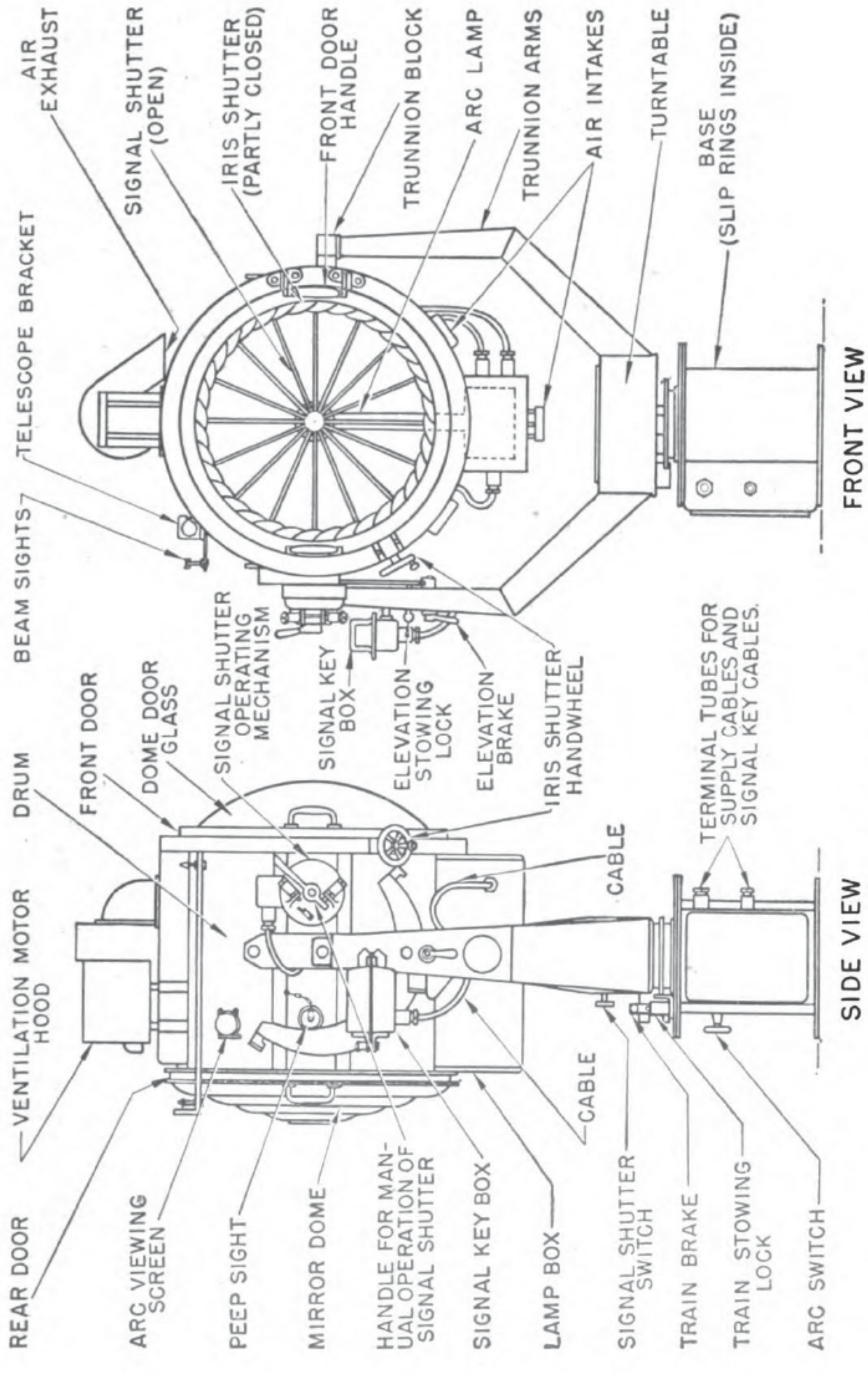


Figure 141.—The 24-inch searchlight.

The high intensity arcs require ventilation systems at all time to prevent overheating.

SEARCHLIGHT CONSTRUCTION

The arc and reflector are housed in the DRUM, which is supported on TRUNNION ARMS so that it can be tilted, to elevate or depress the beam. The BASE supports the trunnion arms so they can rotate. The drum is thus mounted so the light beam can be trained as well as elevated.

The power supply is brought up to the light through slip rings and brushes inside the base, thus permitting continual rotation in either direction. In some bases the power is brought up by flexible cables. These cables must have a long loop left in order to permit rotating the searchlight. This light can be only rotated one and a half revolutions in either direction.

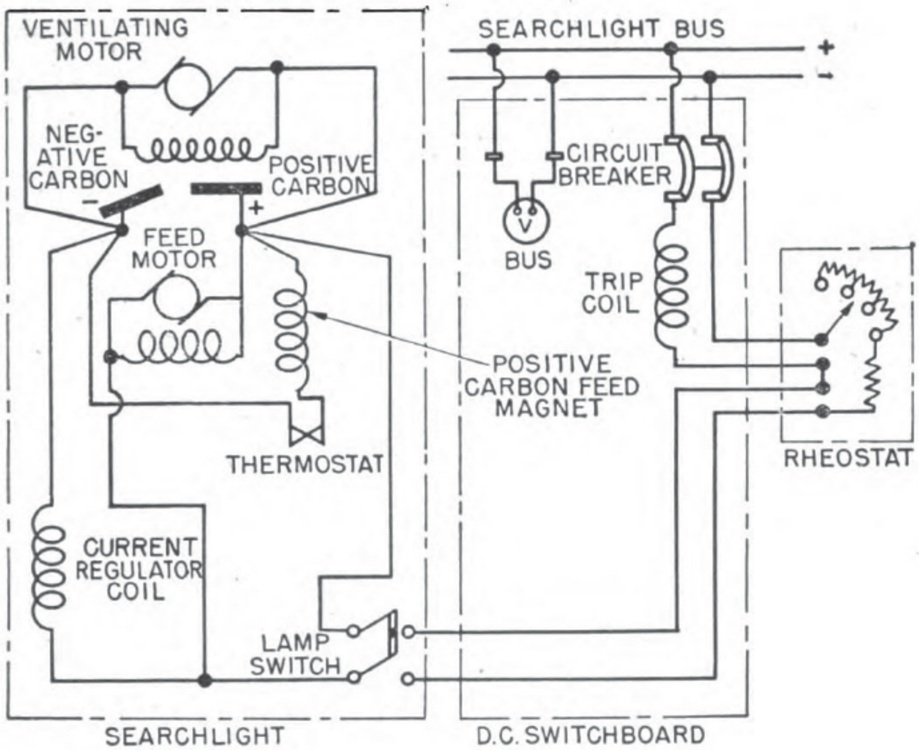
Trunnion Arm. The trunnion arms support the main body of the searchlight. The drum is mounted on ball bearings located at the tops of trunnion arms, allowing for free elevation and depression of the lamp. A locking device is on the trunnion arm to secure the light in elevation and depression.

The trunnion arm rides on ball bearings mounted on the top center of the base, to allow rotation of the lamp in train. A locking device is provided on the base for securing the light in train.

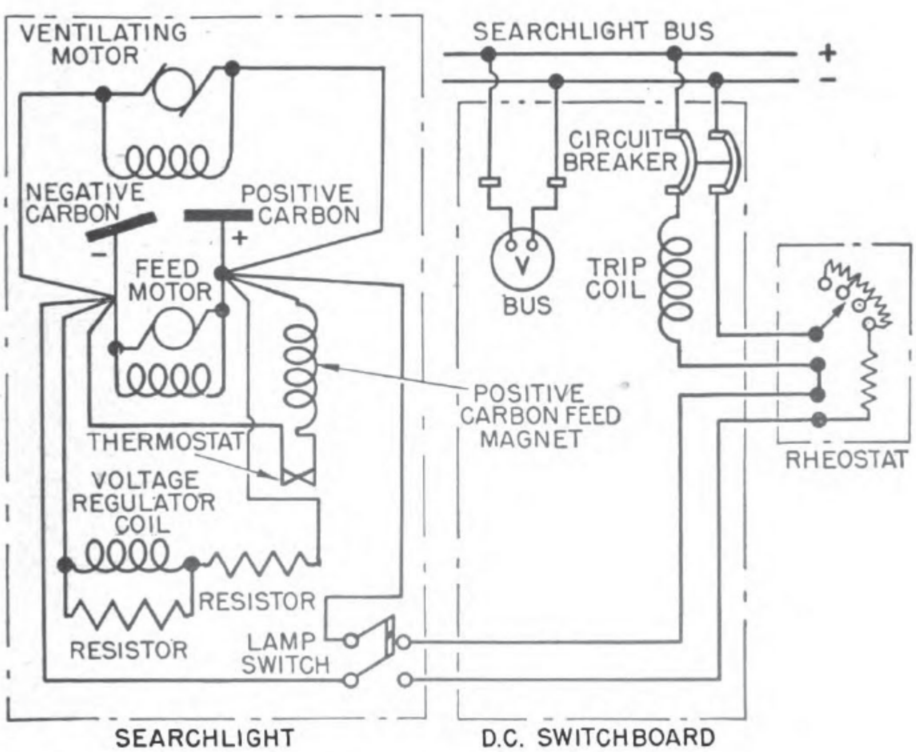
Drum. The drum is the main body of the searchlight and consists of a barrel and access doors. The ventilating motor and shutter usually are mounted on or in the drum.

Vent Motor. The ventilation motor is located in a hood mounted either on the top or bottom of the barrel. The motor is connected in parallel with the arc circuit so that as soon as the lamp switch is closed the motor runs. Notice circuit of wiring in figure 142.

Arc Image Screen. The arc image screen is located near the top of the barrel. It contains a lens system and a ground glass screen. The screen gives the operator an indication of the condition of the arc. A marker on the ground glass screen indicates the proper position for the positive carbon. The arc image screen does not give a direct view of the arc, only an image. Figure 143 shows the correct and incorrect positioning of the carbons as viewed in the screen.



CURRENT CONTROLLED LAMP



VOLTAGE CONTROLLED LAMP

Figure 142.—Wiring circuit for 24-inch searchlight.

Arc Lamp. The lamp consists of the support and carbon feed mechanisms as illustrated in figure 144. The COLUMN is the upright which supports the two feed heads, and acts as a return for the negative side of the arc current. The column is hollow and allows air to flow through it to cool the positive head.

Positive-head. The positive head is the mechanism which supports, rotates, and feeds the positive carbon. These functions are all automatic. The positive head has metal brushes to conduct the current to the carbon.

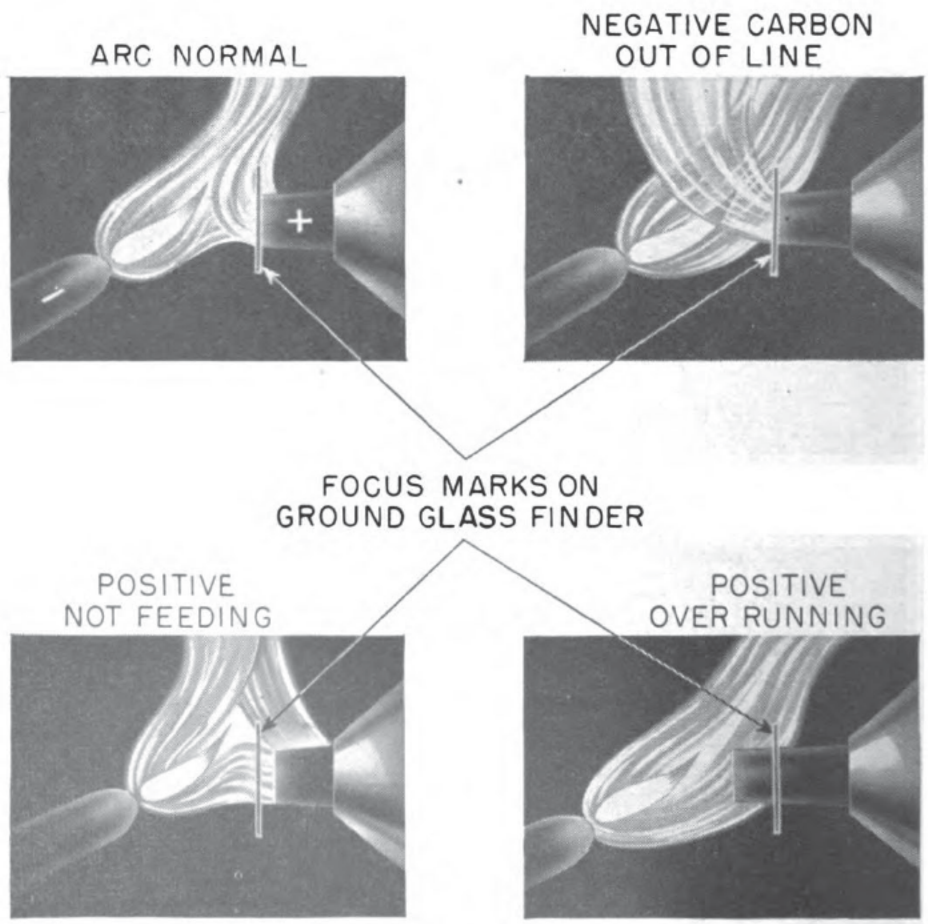


Figure 143.—Views of carbon position.

Obdurator. The obdurator is the metal shield on the positive head. It prevents the heat of the arc from reaching the gear and other exposed mechanism of the positive head. It also helps direct the light rays back to the reflector.

AUTOMATIC FUNCTIONS

The lamp has five automatic mechansims. They are:

Forced draft ventilation.
Positive carbon feed.
Rotation of positive carbon.
Negative carbon feed.
Automatic arc striking.

FORCED DRAFT VENTILATION

The ventilation motor is usually a motor of approximately $\frac{1}{12}$ horsepower connected across the arc circuit. As soon as the lamp switch is closed the vent motor is energized. In operation of the searchlight, the first thing to check is the ventilation.

POSITIVE CARBON FEED

The ball of vapor is the main source of light and must be kept at the focal point of the reflector. The focal point is the point where all light rays from the ball of vapor will be reflected back in parallel lines.

As the positive carbon burns back, the luminous ball of vapor will move out of the focal point. Therefore, some means must be made to keep the luminous ball of vapor at the focal point. This is accomplished by feeding the positive carbon forward as fast as it burns away.

The positive feed system contains a thermostatic switch, a solenoid, a lever and gear system. The power to rotate the positive head is furnished by the feed motor. The feed motor is connected across the arc circuit and runs when the lamp switch is closed.

The thermostatic switch in figure 145 is made of two metal strips welded together. When heated, one strip expands faster than the other and closes the circuit to the positive mechanism. When the positive carbon is in the proper position the heat rays from the arc vapor do not fall on the bimetallic strip. The switch will then be open and cuts off the feed current. As the carbon burns back the heat rays once more strike the bi-metallic strip, closing the feed circuit and feeding the positive carbon forward.

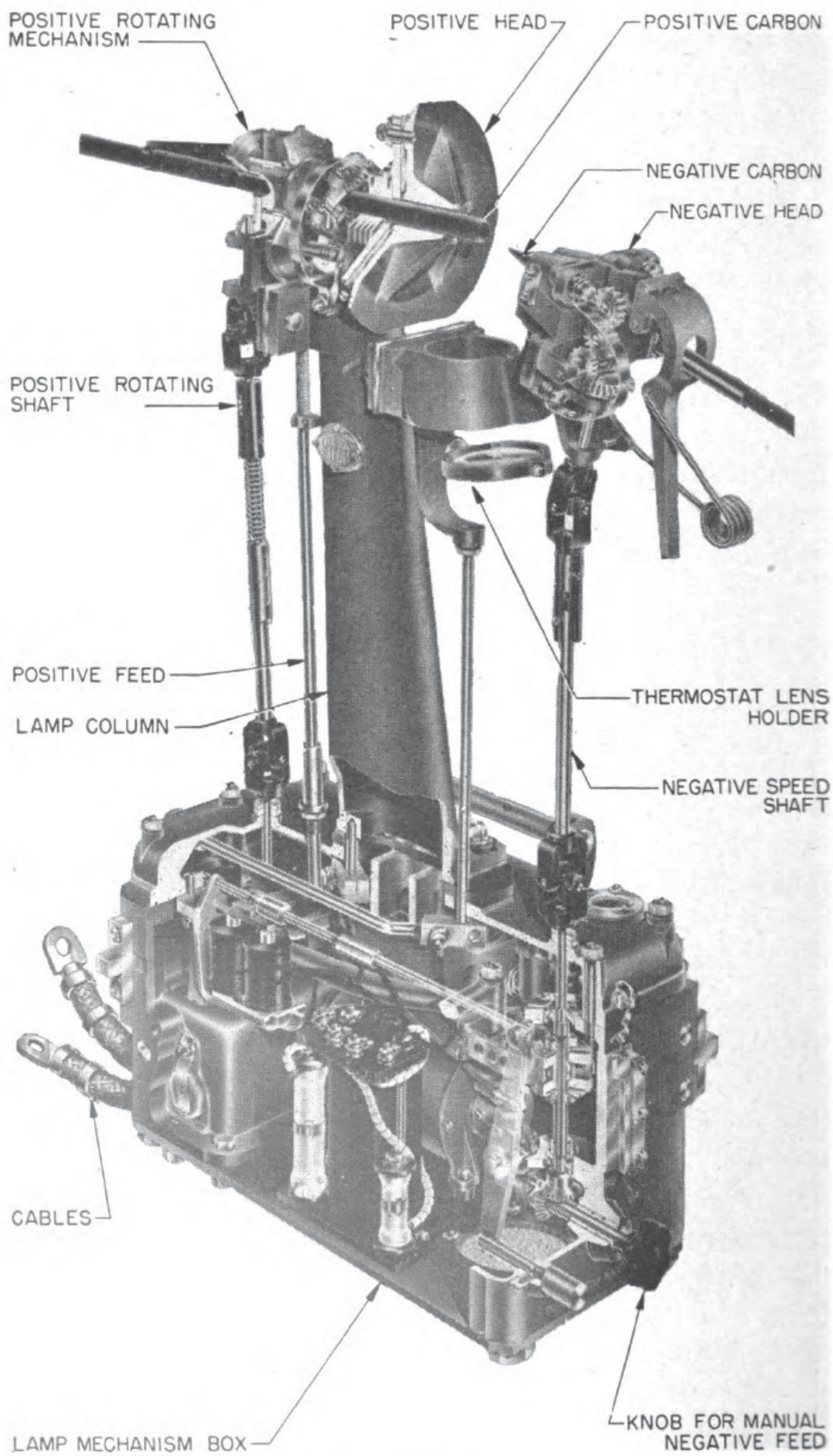


Figure 144.—Searchlight lamp mechanism.

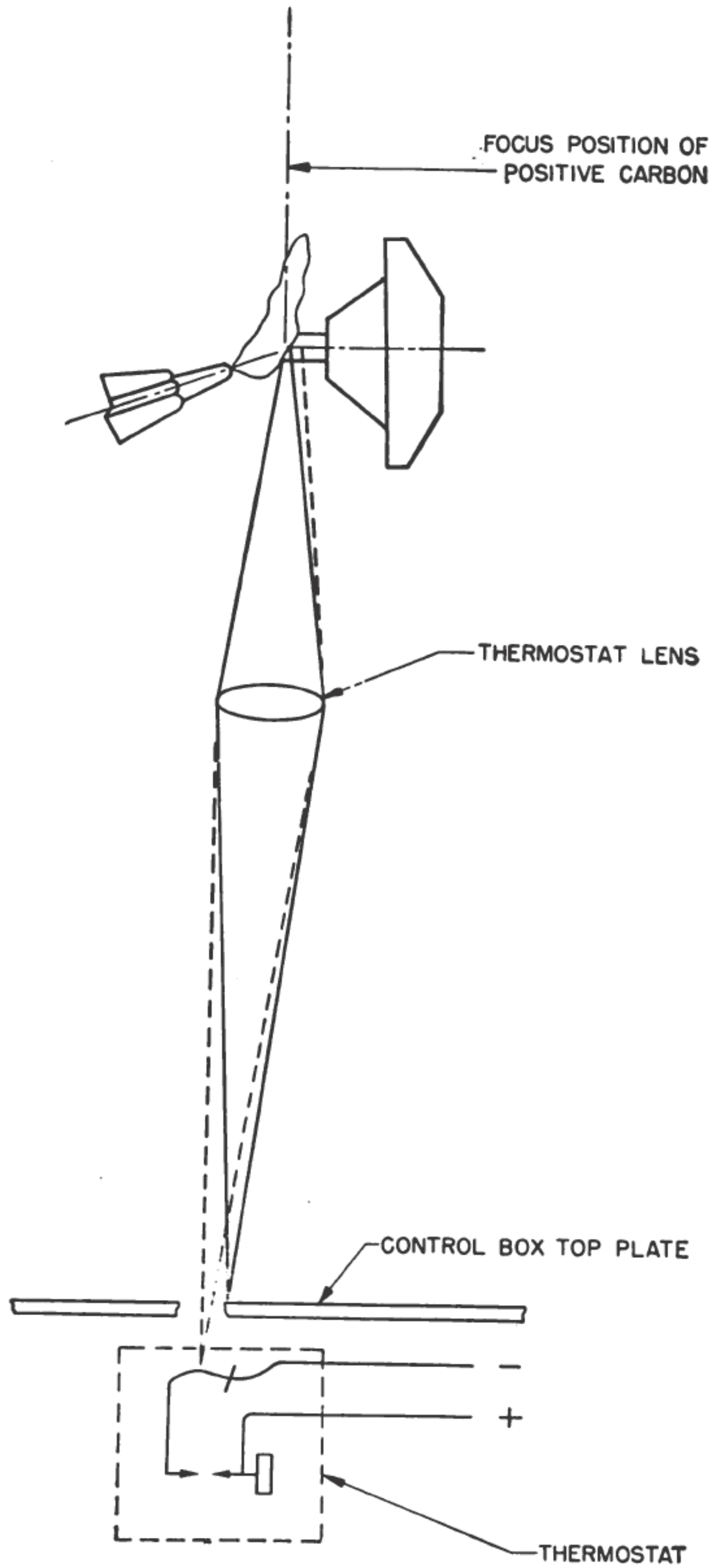


Figure 145.—Thermostatic switch, positive feed mechanism.

ROTATION POSITIVE HEAD

The positive carbon must be rotated all the time in order to keep the crater that holds the ball of luminous gas symmetrical. The feed motor is connected across the arc circuit so that the motor runs all the time the switch is closed. The positive head mechanism is geared directly to the feed motor. The positive head rotates as long as the light is in operation.

PEEP SIGHT

The peep sight is a small circular opening with a colored glass window to give the operator a direct view of the arc.

REFLECTORS

The reflector is a parabolic mirror which collects the light rays and reflects them in a parallel beam. Two types are in use, glass and metallic.

Glass Reflector. The glass reflectors are made of optical glass with the reflecting surface coated with silver. It is efficient but has two disadvantages: first, breakage due to intense heat in drum and due to shock; and secondly, the silver peels. This reflector should be cleaned only with alcohol and precipitated chalk.

Several metals such as chromium steel, coated aluminum and other alloys are used in manufacturing the METALLIC REFLECTOR. They are not subject to breakage or peeling. This reflector may be cleaned with bright work polish or any polish not containing an abrasive. In cleaning NEVER USE A CIRCULAR MOTION—always WIPE FROM the CENTER OUT.

SHUTTERS

Shutters are provided so the light beam may be secured without securing the lamp. They are mounted in the front of the barrel and are of two types— the VANE SHUTTER and IRIS SHUTTER.

The IRIS SHUTTER is light proof. It can be operated manually or by a control motor. This shutter is too slow to be used as a signal shutter. It should be cleaned and lubricated according to manufacturer's instructions.

The VANE type SHUTTER is used for signaling and is primarily a speed shutter. May be operated by manual control or by an automatic key. This shutter is not fully light proof.

RHEOSTAT

The rheostat has a low resistance and high current carrying capacity. One of its most important functions is to prevent a direct short circuit when the arc is first struck. It should be set for the proper operating current of the searchlight, and after its initial setting, should not require adjustment unless a change in the operating current is made.

CURRENT CONTROL NEGATIVE FEED

Feeding of the positive carbon is automatically controlled so that the crater is always at the focus of the reflector. The negative carbon feed is also automatically controlled, to keep the arc length constant. Two types of automatic negative feed are used—CURRENT and VOLTAGE types.

A CURRENT CONTROL negative feed system may be identified by coil wound with heavy strip copper and connected in series with the arc circuit. The current control feed system depends upon a varying current through the arc to actuate the system. The equipment consists of a current coil and plunger which regulate a motor drive for feeding the negative electrode. One end of a pivot arm is attached to the plunger and the other end of the arm is attached to a spring. The current coil is in series in the negative side of the arc circuit.

When the lamp switch is first closed, a very small current flows. This allows the spring to overcome the pull of the current coil, and pull the lever arm down so as to engage the high speed forward feed. The negative carbon is fed forward until it makes contact with the positive carbon. When the carbons strike, there is a high rush of current. This high current causes the current coil to overcome the pull of the

spring and engage the reverse high speed feed, thus pulling the negative carbon back and drawing out the arc. When the pull of the current coil and spring tension are in balance the negative carbon will cease to feed.

Any change in arc length after the arc is struck will be taken care of by the low speed gears. The action of the current coil is the same as in the high speed feed except the feed lever engages the low rather than the high speed gears.

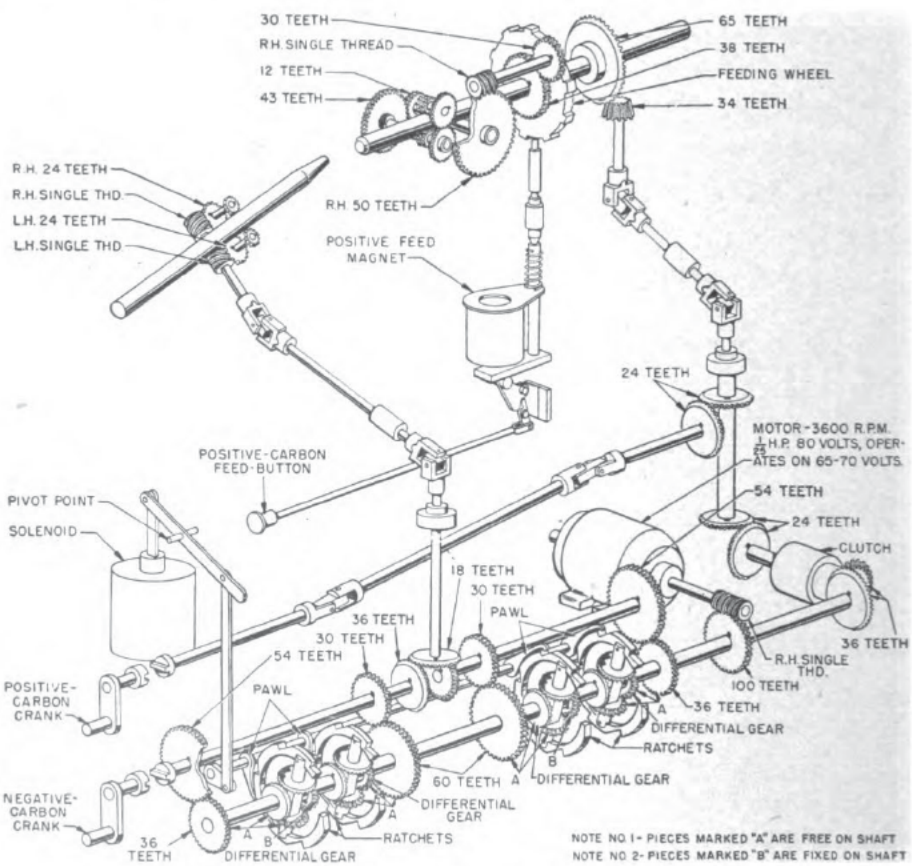


Figure 146.—Positive carbon feed drive mechanism.

If the negative carbon were fed too far forward the arc current would increase, causing the coil pull to overcome the pull of the spring tension and engaging the slow speed reverse gears to feed the negative carbon back until the arm balances.

In a current control negative feed system INCREASING the SPRING TENSION will DECREASE the ARC LENGTH and decrease of the spring tension will increase the arc length.

VOLTAGE CONTROL NEGATIVE FEED

In the VOLTAGE CONTROL negative feed system, the voltage drop across the arc circuit operates the system. It consists of a voltage regulator coil, plunger, pivoted arm with a spring attached to the opposite end of the pivot arm. As soon as the lamp switch is closed there is a high voltage drop across the arc circuit allowing the coil pull to overcome the spring tension and feed the negative carbon forward. Upon striking the arc there is a high rush of current, causing a low voltage drop across the arc circuit, pulling the arm down and engaging the high speed reverse feed. The negative carbon feeds back until the pull of the coil and the spring tension just balance. Any further change due to carbon burning back will be taken care of by the slow speed units.

The voltage control system can be identified by looking for a regulator coil. Voltage control will have many turns of fine wire connected in parallel with the arc circuit. On a voltage control searchlight if the SPRING TENSION is INCREASED the ARC LENGTH INCREASES; if spring TENSION is DECREASED the ARC LENGTH DECREASES.

MANUAL CONTROL

Manual control gear is installed on all searchlights so the searchlight may be operated in case of failure of the automatic system. All of the automatic functions except ventilation can be operated manually. The manual control gear has two small cranks located on the back of the lamp box; one controls rotation of the positive head, the second controls the feed of the negative carbon. A push button controls the feed of the positive carbon.

ADJUSTMENTS

The angle of the negative carbon in relation to the positive carbon must be correct. If the angle is too great or too small the crater of the positive carbon will burn off on one side and allow the ball of vapor to escape. See the lamp instructions book for the correct setting and method of adjustment.

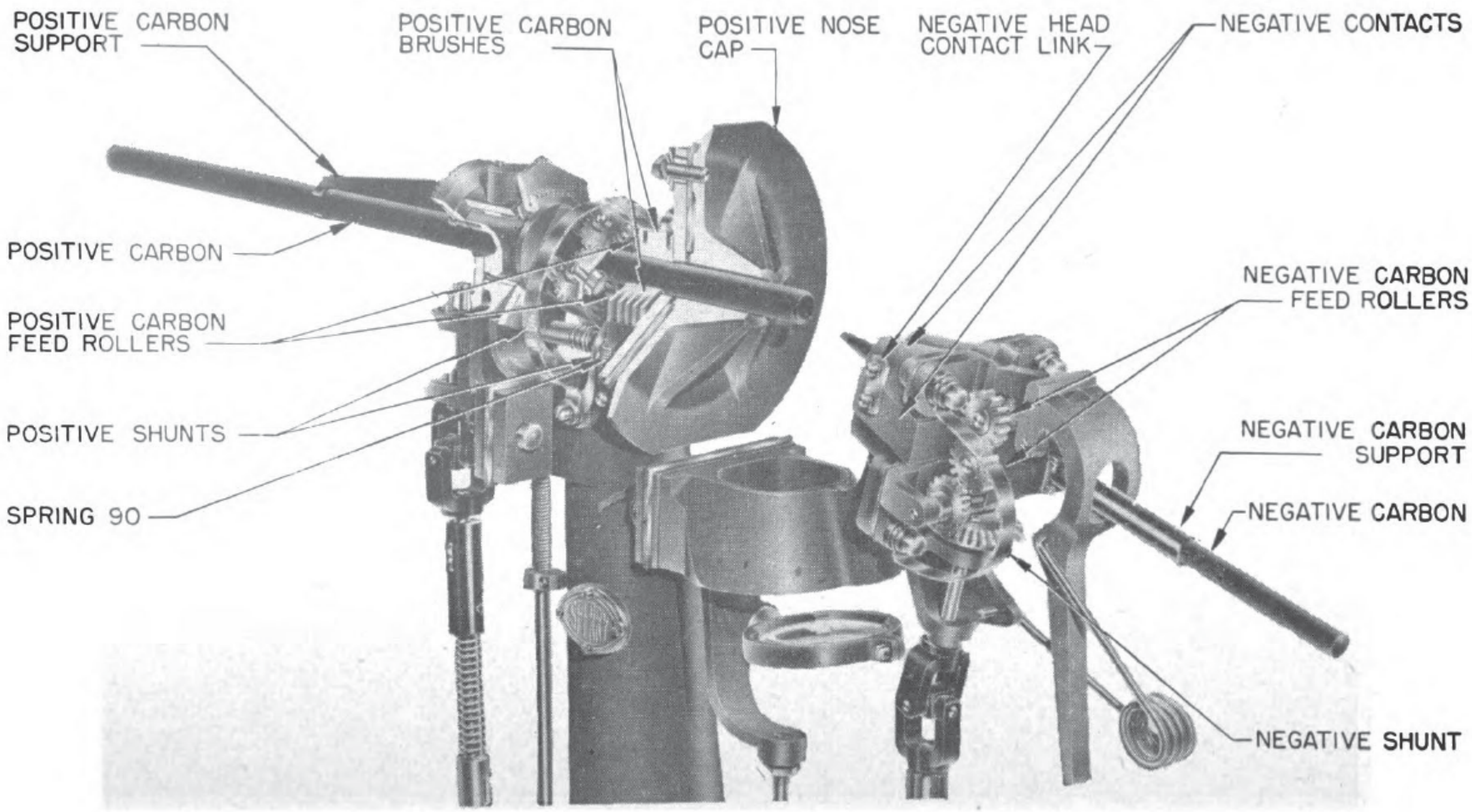


Figure 147.—Carbon feed heads for Sperry 36-inch searchlight.

ADJUSTMENT OF CARBON BRUSH PRESSURE

A proper contact between the heads and the carbons is necessary. If brush pressure is too great the carbons will stick and not feed properly and if too loose will not give good contact. When correctly set it should take a pull of 8 to 10 ounces to slip the carbons out of the head with the feed rollers raised.

ADJUSTMENT OF POSITIVE CARBON PROJECTION

The positive carbon must project a distance of 9/16-inch for for the 24-inch light, 15/16-inch for 36-inch light, in front of the positive head. This prevents the noses from burning and assures proper focus. To make this adjustment allow the searchlight to operate several minutes. Then secure the light and measure the distance from the positive carbon tip and the positive nose. If this distance is incorrect, the procedure for adjusting follows.

If the positive carbon is not projecting out far enough shift the lens, figure 145, in the direction you wish the carbon to feed. Shift lens only about 1/16 inch at a time. After the lens has been shifted the lamp must be operated several minutes, and rechecked. This must be repeated until the projection is correct.

ADJUSTMENT OF ARC LENGTH

The first step in adjusting the arc length on a current control searchlight is to determine the proper operating amperage. You can find this in the instruction book on the light. If the switchboard does not have an ammeter in the arc circuit, connect in a portable ammeter. If the arc current is too high, decrease the spring tension. This will lengthen the arc and decrease the arc current. If the arc current is too low increase the spring tension. This will decrease the arc length and increase the arc current.

For adjusting a voltage controlled searchlight feed determine the proper arc voltage. If the switchboard does not have a voltmeter for the searchlight, connect a voltmeter

across the arc circuit. If the arc voltage is too high, increase the spring tension. If the arc voltage is too low, decrease the spring tension. Always CONSULT the INSTRUCTION BOOK WHEN MAKING ADJUSTMENTS.

FOCUS

After the preceding adjustments have been made, the lamp should be focused. A focus screw on the back of the lamp box moves the entire lamp mechanism toward or away from the reflector. Operate the light for several minutes then secure and measure the positive carbon tip projection. Then measure the distance from the tip of positive carbon to the center of the reflector. This distance should correspond with the focal length given on the reflector.

CARBONS

In 24-inch searchlights, a pair of carbons, at 75 amperes, will last approximately 105 minutes; in a 36-inch light at 150 amperes, about 105 minutes and at 195 amperes, about 45 minutes. Spare carbons should be stored in original containers in a dry clean space. See *BuShips Manual* for full data.

PRECAUTIONS FOR RECARBONING

Always MAKE SURE LAMP SWITCH IS OFF WHEN RENEWING CARBONS.

IF LAMP IS HOT USE GLOVES AND PLIERS to renew carbons.

CHECK CARBON to make sure it is not cracked or warped.

Always START an operation WITH COMPLETE NEW SET OF CARBONS. Never use a set of stubs. After renewing carbons operate the light for about three minutes to form the crater in the positive carbon.

REAMING POSITIVE AND NEGATIVE NOSES

The positive and negative noses should be reamed when needed to remove carbon and other obstruction to insure freedom of carbon to feed. Reamers are furnished as spare parts. The following precautions should be followed: In reaming always hold reamer straight, make sure feed rollers and brushes are lifted, and IF REAMING WHILE LAMP IS HOT

NEVER ALLOW REAMER TO STOP moving UNTIL NOSE IS COMPLETELY REAMED. This is to prevent reamer from becoming stuck as the metal cools.

CLEANING REFLECTORS AND DOME

The reflector and dome glass should be cleaned each time after the light is used. NEVER USE POLISH CONTAINING ABRASIVES.

Use mixture of denatured alcohol and precipitated chalk to clean reflector; the mixture should consist of three ounces of chalk to ½ pint of alcohol. This paste may be removed with cheese cloth. NEVER USE A ROTARY MOTION. Always POLISH FROM THE CENTER OUT. Use a cloth to remove residue of carbons from the burning interior of drum. This residue is a white powdery ash. A small paint brush or painter's duster serves as well to remove carbon particles from the thermostat lens and top of lamp.

LUBRICATION

The manufacturers instruction book gives information for lubricating base, trunnion arms, and lamp. Grease or oil should never be used on the heads. To lubricate heads use a mixture of flake graphite and kerosene at least once a week. The iris shutter should be given a light coat of graphite and kerosene once a month.

PERIODIC TESTS, INSPECTIONS AND CLEANING

AFTER EACH PAIR OF CARBONS—

Wipe reflector, glass door and thermostat lens.

AFTER EXTENDED RUN—

Clean interior of drum, thermostat window and lens and the lamp mechanism.

As soon as the reflector has cooled, clean the reflector and front door glass.

AFTER FIRING—

After each period of firing of the ship's batteries, inspect all searchlights.

DAILY—

Test local mechanical gear for training and elevating light, then the remote control or distant mechanical control gear.

Check remote electrical control gear on searchlight.

Operate each lamp long enough to dry out drum and test functioning of lamp mechanism.

Check ready searchlight for full pair of carbons.

At sea and during damp weather, energize remote control electrical equipment to insure dryness.

WEEKLY—

Clean reflector and front door glass.

Test remote control equipment.

Clean interior of drum, thermostat, window and lens, and lamp mechanism.

Check nose caps for insulation to heads and to ground.

Examine exposed gears and bearings for lubrication and for freedom from dirt, sand and grit.

MONTHLY—

Remove, examine and clean the metal contact blocks which conduct current to the carbons.

Clean carbon feed rollers.

AFTER 50 HOURS OF OPERATION OR QUARTERLY—

After 50 hours of operation and not less than once each quarter, remove the lamp from the drum, overhaul, reinstall and reset the lamp.

YEARLY—

Inspect, lubricate, and repair equipment in the base.

QUIZ

1. Complete the following statements:
   (a) The size of a Navy searchlight depends on the diameter of the ______.
   (b) The 36-inch and 24-inch light have a ______ source of light.
   (c) The 12-inch light has an ______ ______ light source.
   (d) 36-inch searchlights are used primarily for ______.
   (e) 24-inch searchlights are used primarily for ______.

(f) 36-inch light have ______ ______ for elevation and train.

(g) A navy searchlight must:

1. Have a beam free of ______.
2. Have a beam of ______ color.

(h) Most Navy searchlights can:

1. train through ______ degrees.
2. elevate up to ______ degrees.
3. depress down to ______ degrees.

2. Complete the following statements:

(a) To start a carbon arc the carbon electrodes must first ______.

(b) As the arc electrodes are drawn apart current is conducted across the gap by carbon ______.

(c) The crater is a depression in the positive carbon in which the carbon ______ concentrates.

(d) The crater must be positioned at the ______ of the searchlight reflector.

3. What is the difference between high intensity and low intensity arcs?
4. Why must high intensity arcs be ventilated at all times?
5. How is power brought into the light to permit rotation of searchlights in train?
6. Complete the following statements:

(a) Navy searchlights consist of:

1. A ______ to house the light source and reflector.
2. ______ to support the drum so it can be elevated.
3. A ______ to support the trunnion arms so they can be rotated to train the light.

(b) The searchlight drum has:

1. A ______ for the main body.
2. Access ______ to get at the lamp and reflector.
3. ______ motor to prevent overheating of the lamp.
4. Arc ______ screen to indicate condition of the arc.

(c) The arc lamp consists of:

1. A ______ to support the carbon feed mechanism.
2. A ______ to support, rotate, and feed the positive carbon.
3. A metal ______ or obdurator to keep the heat of the arc from the positive head.

(d) The arc lamp has automatic mechanisms for

1. Forced draft ______.
2. Positive carbon ______.
3. ______ of positive carbon.
4. Negative carbon ______.
5. Starting the ______.

(e) The positive carbon is automatically fed forward to keep the luminous vapor of the arc at the ______.

(f) The positive carbon is automatically fed forward by a motor controlled by a ______ switch exposed to heat from the arc.

(g) The positive carbon must be continuously rotated to keep the arc crater ______.

(h) The positive carbon is constantly rotated by the ______ motor.

7. Complete the following statements:

(a) The reflector of a searchlight is a mirror of ______ shape which collects the light from the arc and reflects it in a parallel beam.

(b) Reflectors are made of:

1. Optical glass coated with ______.
2. Metals such as ______.

(c) In cleaning reflectors always wipe from ______ ______.

8. Complete the following statements:

(a) Shutters are used to ______ the light beam while the lamp is on.

(b) The iris shutter is too ______ for signalling.

(c) The vane type shutter is used for signalling because of its ____.

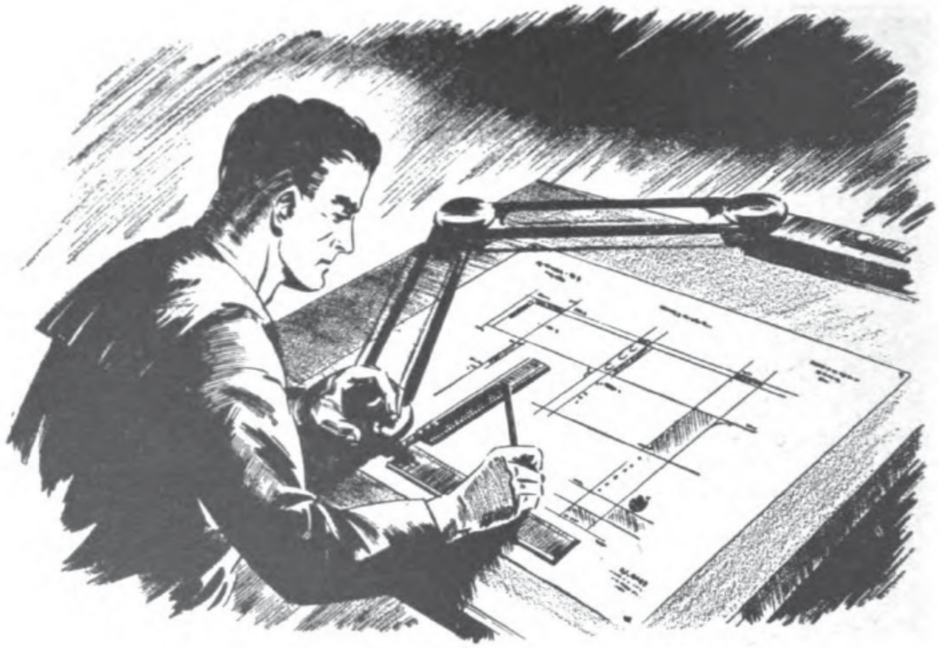
9. Complete the following statements:

(a) In a current control negative feed, the feeding of the negative carbon is controlled by balancing the pull of a solenoid, energized by the ______ current, against the tension of a spring.

(b) In a current control negative feed, when the solenoid pull and spring tension balance, the negative carbon ______ feeding.

(c) In a current control negative feed system, increasing spring tension will ______ arc length.

10. Complete the following statements:
   (a) In a voltage control negative feed, the feeding of the negative carbon is controlled by balancing the pull of a solenoid, energized by voltage drop across the ______, against a spring tension.
   (b) In a voltage control negative feed, increasing spring tension will ______ arc length.
11. Complete the following statements:
   (a) To keep the positive crater from burning off on one side adjust the ______ between negative carbon and positive carbon.
   (b) When carbon brush pressure is properly adjusted it takes a pull of ______ ounces to slip the carbons out of the head with feed rollers raised.
   (c) Positive carbon projection must be adjusted to assure proper ______.
   (d) Arc length is adjusted by changing spring tension of the ______ carbon feed.
   (e) To adjust lamp focus, move the lamp mechanism toward or away from the ______.
12. Complete the following statements:
   (a) Search light carbons will last:
      1. 24-inch, ______ minutes.
      2. 36-inch, at 190 amperes, ______ minutes.
   (b) After renewing carbons operate light for about ______ minutes to form positive crater.
   (c) If reaming positive or negative noses while hot, never allow reamer to ______, to prevent reamer sticking as metal cools.
   (d) To clean reflectors:
      1. Use mixture of 3 ounces ______ to ½ pint ______.
      2. Polish from ______.
      3. In polishing never use ______ motion.
   (e) In lubricating lights, never use grease or oil on negative or positive ______.
13. Name the tests, inspections and cleaning to be given searchlights
      (a) daily
      (b) weekly



CHAPTER 16

BLUEPRINT READING AND SKETCHING

INTRODUCTION

Electrical wiring drawings or blueprints are maps which show you the location and circuit connections of every piece of electrical equipment aboard ship. Blueprints properly used are an invaluable aid in "trouble shooting", in other words, in isolating faults in an electrical circuit. This is undoubtedly the most important work of the naval electrician. You should therefore study the training course *Use of Blueprints* (NavPers 10621) to get a basic understanding of how blueprints are made and used. Then read this chapter and you will know all the information that goes into Navy wiring blueprints and how to use it.

Mechanical drawing in the form of sketching frequently is used by the electrician in the event some electrical part is to be constructed in one of the ship's shops. A correctly made drawing will give a complete pictorial description of the part and therefore aid greatly in its construction. For this reason a brief review of what you learned in *Use of Blueprints*, and a few suggestions as to the layout of simple mechanical drawings, are included in this chapter.

PRODUCTION, CARE, AND FILING OF BLUEPRINTS

Blueprints are made from drawings in much the same manner that photographs are made from negatives. The negative for the blueprint is known as a TRACING. It is made by placing a sheet of special white, semi-transparent paper on cloth over the working drawing. Everything on the drawing is traced on the tracing cloth with black waterproof ink or a special black pencil. Some drawings are made directly on the tracing material in pencil, then traced with ink or the special black pencil. This short cut saves time and material and is satisfactory for most jobs.

To produce a blueprint the tracing is placed on a pane of clear glass mounted in a special frame. The tracing is covered with a sheet of chemically coated, light-sensitive blueprint paper. A padded back is secured behind the blueprint paper to keep the two sheets together. The front of the frame is then exposed to a strong light, which projects through the tracing onto the coated side of the blueprint paper.

After proper amount of exposure, the print is removed and washed in clear water to remove the unexposed chemical. The exposed portions of the print paper turn a deep blue during the washing. The lines will be white.

Blueprints are not always blue. They may be white, brown, black, gray, or other colors. The difference lies in the kinds of light-sensitive chemical on the paper, and in the development processes required for that chemical. But the process of making the print is the same—you project a light through the tracing onto the light-sensitive paper.

Blueprints are valuable permanent records and if properly cared for can be used many times. Listed below are a few simple rules for getting the best results from your blueprints.

KEEP them OUT OF STRONG SUNLIGHT, as they may fade.

DO NOT ALLOW them TO GET WET or grease smudged.

Do not pencil or crayon notations without proper authority. If you should get instructions TO MARK A BLUEPRINT, USE A YELLOW PENCIL. Black pencil marks are hard to see on a colored background.

Frequently used blueprints should be glued to a sheet of cardboard. Cover the face with a coating of clear shellac.

FILING OF BLUEPRINTS

Blueprints are filed in the log room. The bulk of the electrical equipment aboard ship is provided by the Bureau of Ships and is shown on Bureau of Ships drawings. The Bureau of Ships system of designating and filing blueprints is described in the next few paragraphs. Turret and mount electrical installations are furnished by the Bureau of Ordnance and are shown on BuOrd drawings. The system of designating and filing BuOrd drawings is described following the BuShips system.

For BuShips drawings, all filing will be separated into letter groups. The prints an electrician will work with will be filed in the "S" group, covering Ship Materials. There are 94 separate divisions in the "S" group. A power distribution blueprint would be in group S–62, a lighting distribution print would be in group S–64. To locate the print you desire refer to the *Navy Filing Manual* to determine the division of the "S" group your circuit would be classified under and then look in the files for that division of the group.

Each print of a circuit or piece of equipment installed by a Navy yard will have an index, group, and file number on it.

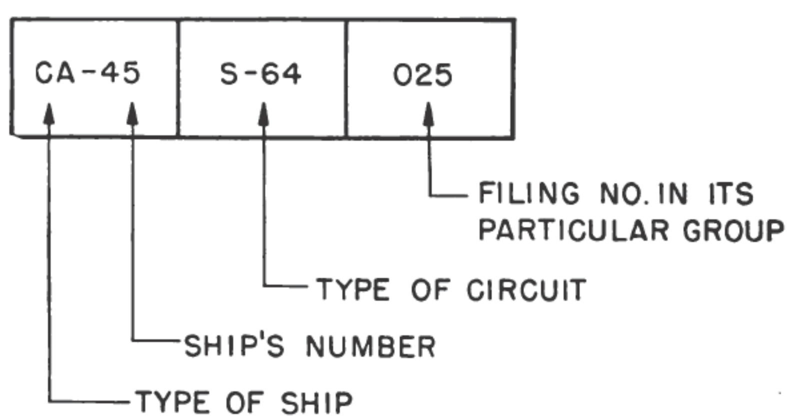


Figure 148.—A blueprint index group and file number.

Figure 148 shows a typical index group and file marking of a BuShips blueprint. The letters on the left denote the type of ship and the number of the ship in that class.

In the center of the box is the circuit classification. The right hand numbers are the file numbers of the group indicated at center.

The index group and file markings of figure 148 indicate that this blue-print is from the heavy cruiser Wichita, it is a lighting distribution print, and it is to be filed as #25 in the S–64 group of files.

Bureau of Ordnance electrical drawings cover the electrical equipment and wiring inside a turret or mount and are identified primarily by the serial number of the drawing. The drawing title also tells the mount or turret the equipment is part of, so to find the drawing for a piece of electrical equipment in a mount or turret, you must know the BuOrd designation for that mount or turret. You find this out from the Gunner's Mate, who can also provide you with the ordnance drawings, which are kept in the gunnery officer's office.

FUNDAMENTALS OF DRAFTING

Before you can thoroughly understand a blueprint and be able to sketch a drawing of your own, you must first know the types of lines used. Figure 149 illustrates the different lines.

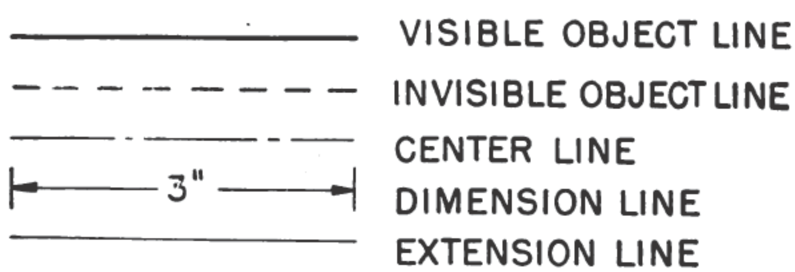


Figure 149.—Types of lines in making drawings.

The VISIBLE OBJECT lines represents visible edges, the outline of the object. If a surface is hidden from sight but needs to be shown in some manner, use an INVISIBLE OBJECT line. This line will show the location and extent of the hidden surface, and by rendering it broken, will indicate that the surface represented is not from this view. Visible and invisible object lines are used in figure 151.

Whenever the object drawn is symmetrical about a com-

mon center, such as a shaft, a hole drilled in a casting, or any other circular object (that is just alike on both sides of the center) a CENTER LINE is used to indicate the axis of the hole or shaft. It is made of alternate dashes and single dots. Center lines should be drawn lightly. If a hole in an object is to be indicated, horizontal and vertical center lines both should be shown.

DIMENSION LINES are light lines having arrowheads at their ends. They are used to show the dimensions of the object. EXTENSION LINES are extensions of object lines. They indicate the limits of a dimension. The OBJECT LINES of a drawing, full or broken, always are heavier than the center, extension and dimension lines. Object lines are described as being number 1 lines in weight and all others number 2 in weight. The use of these lines is illustrated in figure 151.

SYMBOLS

When a draftsman makes an electrical wiring diagram, he uses electrical abbreviations or symbols instead of drawing each piece of electrical equipment in detail. Unfortunately an identical piece of equipment may be represented by an entirely different symbol by different draftsmen. Therefore, a single set of standard symbols are difficult to prepare, but listed here are a few of the more common ones.

Actually there are two complete lists of symbols—ELEMENTARY and SCHEMATIC. The ELEMENTARY SYMBOLS, shown in figure 150, are used on wiring diagrams that SHOW each conductor and all the CONNECTIONS in the circuit. These symbols are more detailed than the schematic symbols. SCHEMATIC SYMBOLS, some of which are shown in figure 154, are used to SHOW the LOCATION and general layout of the circuit. The types of drawings in which the different types of symbols are used are discussed in the later paragraphs on WIRING DRAWINGS.

Notice that no elementary symbols specify watertightness while schematic symbols do. On the schematic list the symbols showing watertightness have a double line. W. T. is the abbreviation for watertight. N. W. T. indicates that the piece of equipment represented is not watertight.

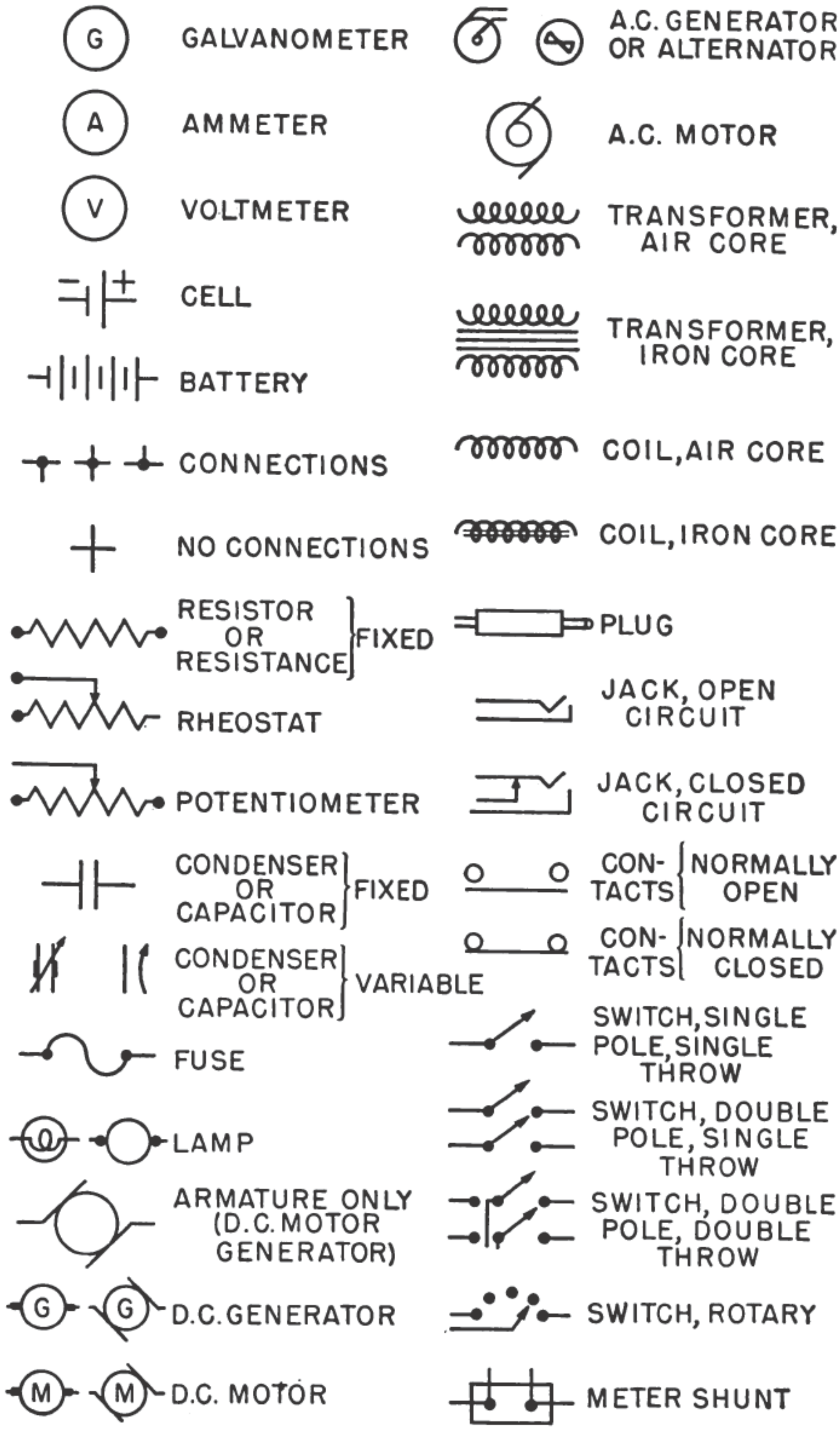
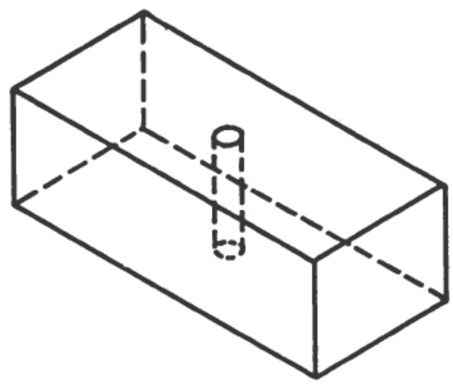


Figure 150.—Electrical symbols.

ORTHOGRAPHICS

A drawing is a plan, sometimes a specification. Drawing is a means of expression, and consequently is a form of language. It is far better to give a machinist's mate a drawing of a sleeve bearing that you wish to have made than to give him an oral description of the bearing.

The clearest method of representing an object is by showing it in ORTHOGRAPHIC views. Orthographic comes from the word "ortho," which means at right angles to. An orthographic view, therefore, is any drawing that shows true



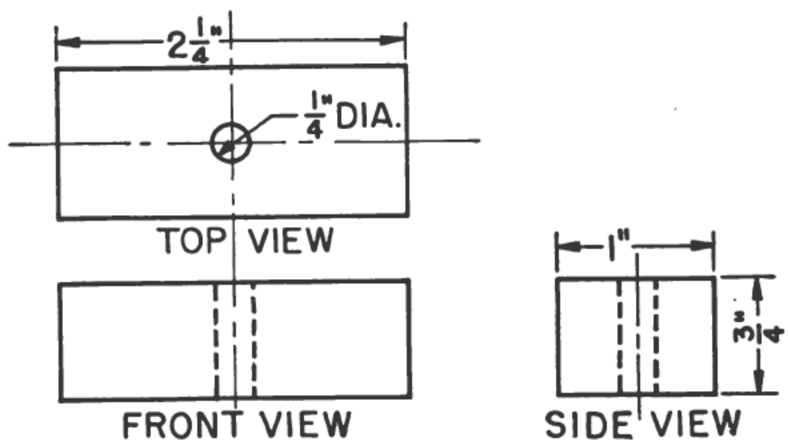


Figure 151.—Views of a block.

size and shape of one surface of an object when that surface is at right angles or perpendicular to your line of vision.

You may make as many orthographic views, as the object has sides. If the object drawn has an irregular shape, that

is all its sides are different, then the drawing will contain a view for each side. Seldom are more than two or three views necessary to give a complete picture of an object. In all cases a correctly made orthographic drawing contains as many views as necessary to give a complete description of an object. Figure 151 is an orthographic drawing of a block. Six orthographic views of this object could be drawn. Careful inspection of the object will reveal that the top and bottom are identical, and that there is no difference between the front and back side, or right and left ends. Therefore, as shown in figure 151, only three views are necessary.

HOW TO MAKE A DRAWING

Following is a list of the general steps to help you in sketching an orthographic drawing. Practice on simple objects first, then try the more difficult.

Study the object and decide the combination of views that will give the best description.

Block in outline views, in proper arrangement, with light construction lines.

Build up the detail of each view, such as representing all invisible edges with broken lines.

Give each view its proper name and dimensions.

Check drawing for any possible errors.

Darken all object lines and erase construction lines which have no further purpose to the drawing.

To satisfy step 1, bear in mind that an orthographic drawing needs only as many views as necessary to give a complete picture of an object.

All orthographic drawings should have the views presented in their proper relation. That is, don't put end views on top, and bottom views on top. Referring to figure 151, you can see that all horizontal measurements on both the front and top views are equal. This is the reason they are drawn IN LINE with each other. The vertical measurements of the front and end views sometimes are different and the arrangement of the views is not always the same, but the same

RELATIVE POSITION of the views in regard to each other always IS THE SAME.

The scale of a drawing refers to the size of the drawing in relation to actual size of the object. Thus when a drawing is made on a scale of 1 inch equals 1 foot, the size of the drawing is one twelfth of the size of the object drawn. Before beginning any drawing determine the scale to be used and make a note of it on the drawing.

ISOMETRICS

Often it is desirable to give a "picture drawing" in conjunction with an orthographic sketch so one may gain an idea of the general shape and size of an object. This type of drawing is called PERSPECTIVE.

A perspective drawing is to show an object exactly as it appears to your eye. A perspective drawing would show the same outline that would appear in a photograph.

Your eye as well as the photograph and perspective drawing tell you things that aren't exactly true. Just recall the last time you looked down a straight stretch of railroad track. Your eyes told you that the tracks came together at a distant point. You knew the tracks were parallel so you didn't believe your eyes. The camera records this deception and since the perspective drawing gives exactly what is seen to the eye, it also registers a lie.

The isometric drawing is similar to the perspective, but all parallel edges are drawn truly parallel. All its lines representing horizontal and vertical lines on an object have true length. Vertical lines are shown in a vertical position, but lines representing horizontal edges are drawn at an angle of 30° with the true horizontal. Vertical lines and lines representing horizontals are known as isometric lines. The picture at the top of figure 151 is an isometric drawing.

Isometrics cannot be used alone for complicated parts or structures, but may be used as an aid in clarifying the accurate orthographic drawings. Remember that no lines except the isometric lines of an isometric drawing can be relied upon for true measurements.

SHIP COMPARTMENTATION AND EQUIPMENT MARKING

The different parts of a ship are named so you can talk about a certain part enabling another person to know exactly what you are talking about.

Knowing how the different decks are numbered, how the compartments are labeled, and how electrical equipment is numbered will enable you to work more readily from a wiring blueprint.

There are two types of decks, COMPLETE DECKS and PARTIAL DECKS. A complete deck is a deck running the full length of the ship and a partial deck is a deck running only part of the length of the ship. Decks are named and numbered according to their location above or below the main deck. The MAIN DECK is the topmost complete deck.

A partial deck that is one deck level above the main deck at the bow is called the FORECASTLE DECK; at the stern, POOP DECK; amidships, UPPER DECK. A partial deck above the main, upper, forecastle, or poop deck and not extending to the side of the ship is called a SUPERSTRUCTURE DECK.

A complete deck below the main deck is called the SECOND DECK. Where there are two or more complete decks below the main deck, they are called the SECOND DECK, THIRD DECK, FOURTH DECK, etc. A partial deck between two full decks where vertical height permits is called a HALF DECK. A partial deck below the lowest complete deck is called a PLATFORM. Where there are two or more partial decks below the lowest complete deck, the one immediately below the lowest complete deck is called the FIRST PLATFORM, the next is called the SECOND PLATFORM, and so on. The space below the lowest platform is referred to as the HOLD. The deck at the bottom of the hold is the HOLD DECK.

Decks are numbered using the main deck as a reference level. The main deck is number 1 deck level. The next deck below the main deck, regardless of its name, is number 2 deck level; the second deck below the main deck is number 3 deck level, and so on down to the hold deck.

The first deck above the main deck is 01 deck level, the

second deck above the main deck is 02 deck level and so on to the topmost deck of the ship.

A half deck takes the number of the deck directly below it. A letter "H" precedes this number to denote a half deck. A half deck located between the main and second decks would be numbered "H2".

As an example of how decks are numbered, consider a ship having a superstructure deck, an upper deck, a main, second, and third deck, a first and second platform, and a hold deck. In addition to these decks there is a half deck between the second and third decks. These decks will be numbered as follows:

Superstructure deck	02	Third deck	3
Upper deck	01	First platform	4
Main deck	1	Second platform	5
Second deck	2	Hold deck	6
Half deck	H3		

COMPARTMENTS

Transverse bulkheads across the ship cut naval vessels into 3 or 4 main sections. These sections are labeled A, B, C, and D, from fore to aft. In a three-section ship, SECTION A extends from the bow to the first transverse bulkhead of the engineering section. SECTION B includes the space from first bulkhead to the after bulkhead of the engineering section. SECTION C comprises the remaining section aft. In a four-section ship, the machinery or engineering space is divided into two parts, sections B and C, with SECTION D comprising the remaining spaces aft.

While the ship is considered as having only three or four main sections, that does not mean that there are only two or three transverse bulkheads. There are many others, all adding to the structure of the vessel and contributing to its compartmentation and watertight integrity.

Compartments aboard ship are given letters and numbers denoting the location and use of the compartment. The following compartment marking is an example:

A—201—*L*

A	2	01	L
Section of Ship	Deck Level	Position of Compartment in the Section	Use of Compartment

Taking the letters and numbers from left to right the first letter indicates the section of the ship the compartment is located in. The first number tells us the deck level. The two numbers following the deck level tell us whether the compartment is located on the port or starboard side of the ship and also give us the position of the compartment fore and aft in the section.

Port side compartments have even numbers, starboard compartments odd numbers. The first compartment forward on the port side of a general section in the ship is given the number 02, the next compartment aft of it on the port side 04, etc. All numbers in each section begin at the forward end of that section.

The letter at the right gives the use of the compartment. The list below is an explanation of the code—

A Storerooms.
B Gun and torpedo battery compartments.
C Ship control and fire control compartments.
E Machinery compartments.
F Fuel compartments.
LUB Lubricating oil storage compartments.
GAS Gasoline compartments.
L Living compartments.
M Ammunition storage compartments.
T Trunks and hatches.
V Void compartments.
W Water compartments.

All compartments and spaces that are bounded completely by watertight, oiltight, airtight, or fumetight structures have their own individual markings. Where a watertight compartment located below the weather deck is divided into two or more airtight or fumetight spaces by air tight or fumetight bulkheads, the appropriate number is assigned the

watertight compartment and each airtight or fumetight subdivision within the compartment is designated by the addition of a suffix to this number. Thus if watertight compartment A–312–L contains fumetight or airtight longitudinal (fore and aft) bulkheads, the space to starboard of this bulkhead is designated as A–312–1L and the space to port as A–312–2L.

A half deck compartment has the letter H directly before the deck level.

Here are some examples:

B–301–E

B	3	01	E
Amidships Section	Third deck	Forward compartment Starboard side	Machinery compartment

B–0102–C

B	01	02	C
Amidships Section	One deck above the main deck	Forward compartment Port side	Ship control or fire control compartment

Compartments such as pump rooms, auxiliary machinery rooms, engine and fire rooms generally extend upwards through two or more decks. These are numbered from

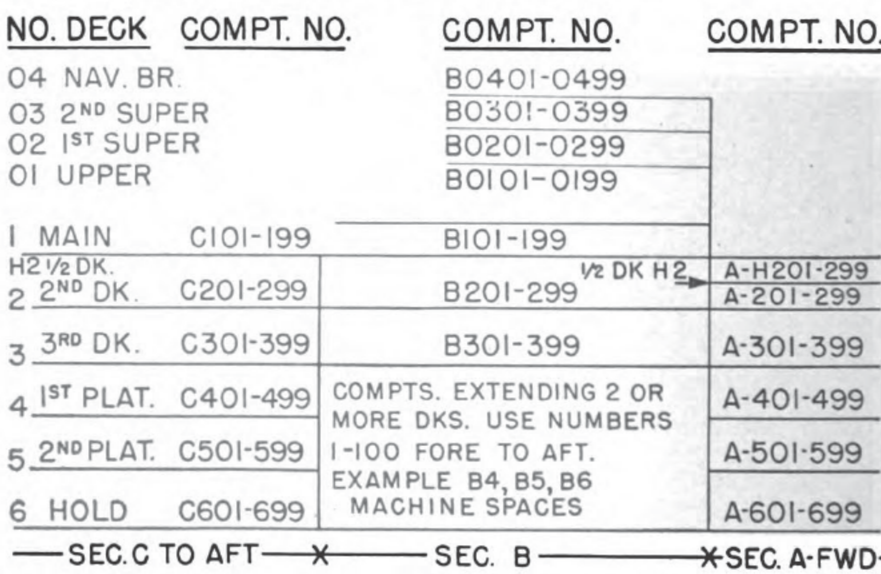


Figure 152.—Deck and compartment numbering system.

forward to aft in order. Their numbers are prefixed by the section letter. For example, a pump room forward might extend two decks, in which case its number would be A–1; the next compartment, extending two or more decks, would be the fire room which would be B–2, followed by the engine room, B–3. Should there be a similar place aft, it might be called C–4. The numbers follow in order, the letters changing according to the section in which the compartment is located. The numbering system for decks and compartments is illustrated in figure 152.

MACHINERY MARKINGS

Every piece of electrical equipment is given three numbers as—

3—46—1

Deck level	Frame	Port or Starboard Position
3	46	1

Here again as in the case of compartment marking, a piece of equipment located on a half deck has a letter H prefixed to the number of the deck level directly below the half deck.

Equipment on the center line does not have the third letter as it is on neither port or starboard side.

If the equipment is between frames, it takes the number of the frame forward.

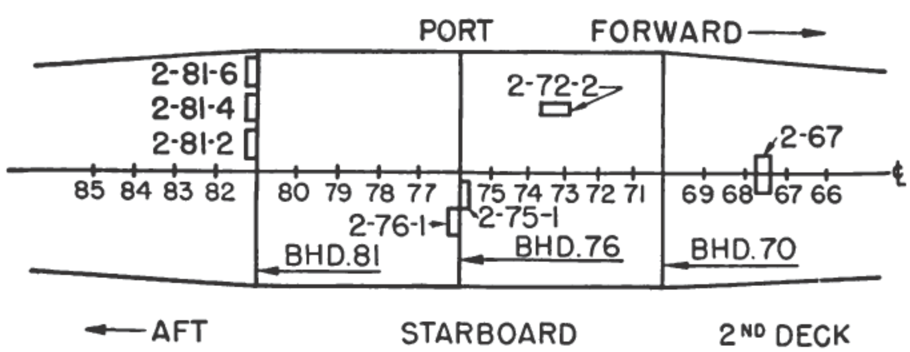


Figure 153.—Method of numbering power panels.

Should there be two or more pieces of equipment located on the same deck, same frame, same side of ship, then the last number denotes position in regards to the center line.

Consider the case as in figure 153 when we have three panels all located on the second deck, frame 81, port side. The panel nearest the center line has the smallest even number, the next panel outboard has the next higher even number, and so on outboard.

Figure 153 is an example of how equipment is marked at various locations. Note that if a piece of equipment straddles a frame it takes the number of the preceding frame. (See panel (2–72–2)).

TURRET AND MOUNT MACHINERY MARKINGS

Every turret and mount is full of mechanical installations which do special jobs such as elevating the guns, hoisting powder or projectiles up to the guns, etc. These installations are furnished by the Bureau of Ordnance and each installation is called an ORDNANCE ASSEMBLY. Each assembly is designated by a name indicating the job it does, and a "Mark" and "Mod" number indicating a particular design of such an assembly. Thus in the 5-inch single mounts on carriers of the MIDWAY class (5-inch Gun Mount Mark 39), these are some of the Ordnance Assemblies you will find: *Elevating Gear Mark 15 Mod 0, Projectile Hoist Mark 6 Mod 0, Power Hoist Mark 6 Mod 0.*

The motor, switches, and other electrical parts associated with each Ordnance Assembly are considered parts of that assembly. Each of these electrical parts has a name plate which tells you what Ordnance Assembly it is part of.

A complete set of drawings for every Ordnance Assembly is furnished by the Bureau of Ordnance to each ship and is kept in the Gunnery Officer's Office. These drawings show where each part of the assembly is located and how it is constructed. So if you want to know where a particular piece of electrical equipment in a mount or turret is located, or how it is constructed, first find out what Ordnance Assembly it is part of. Then ask the Gunnery Officer or Chief Gunner's Mate for the folder of drawings on that assembly. Looking through the drawings in this folder you will find drawings which show the location and construction of the electrical part you are interested in.

ELEMENTARY WIRING DRAWINGS

All shipboard wiring blueprints fall under the three general headings of ELEMENTARY wiring drawings, ISOMETRIC wiring drawings, and wiring DECK PLANS.

The ELEMENTARY wiring drawing is, as the name implies, as simple and detailed as possible. It shows each individual conductor in the circuit and every connection made. It may or may not show the connection boxes themselves. In all Interior Communication (IC) circuits the lugs in each connection box are stamped with the proper lead markings. The elementary wiring diagram shows these lead markings alongside each lead of the circuit.

In the case of an elementary wiring drawing for a controller the drawing often shows the relative position of the various components of the controller. Most elementaries, however, show nothing of the fixtures or cable runs. Because of this, elementaries are not drawn to scale. Elementary drawings use the elementary type of symbols. An elementary drawing would be used to check proper connections in a circuit or to make the initial hook-up. Each elementary wiring blueprint contains one circuit only.

ISOMETRIC WIRING DRAWINGS

Each electrical system has its own ISOMETRIC wiring drawing. If the individual system is not too large, it will be covered by one blueprint. There will be a separate isometric wiring diagram for each IC circuit.

In isometric drawings the decks are arranged in tiers, starting at the bottom with the hold and successively arranged to the bridges and superstructure. Section and divisional bulkheads are shown as well as the bulkheads that divide the deck into the main compartments. The center line is marked with frame numbers every five or ten frames. The outer edge of each deck is drawn with the general outline of the shape of the ship.

All athwartship lines are shown at an angle of 60° to the center line, and the location of compartments as shown by the blueprint gives an accurate idea of the deck arrangement, although not in detail. The purpose of distorting the

athwartship lines is to permit the continuous representation of cables passing between decks. Cables running from one deck to another are drawn as lines at right angles to the center line.

The exact location of fixtures and cable runs cannot be satisfactorily arrived at by use of an isometric wiring blueprint because the locations shown are only approximate. The symbol numbers of the fixtures in the circuit are given and also the cable numbers and sizes. This aids the electrician in associating each circuit with its elementary wiring drawing. An isometric wiring diagram for a turret is shown

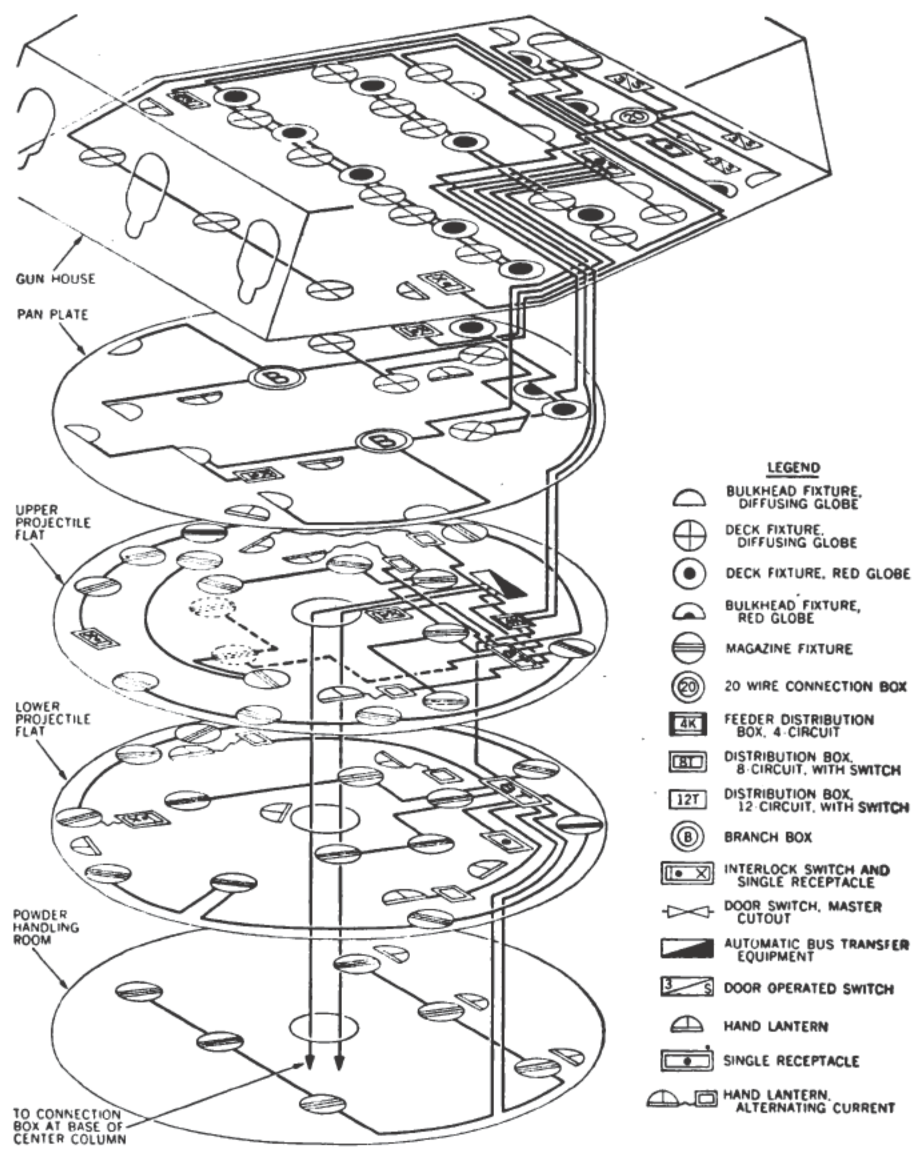


Figure 154.—Isometric wiring diagram for 8-inch turret illumination system.

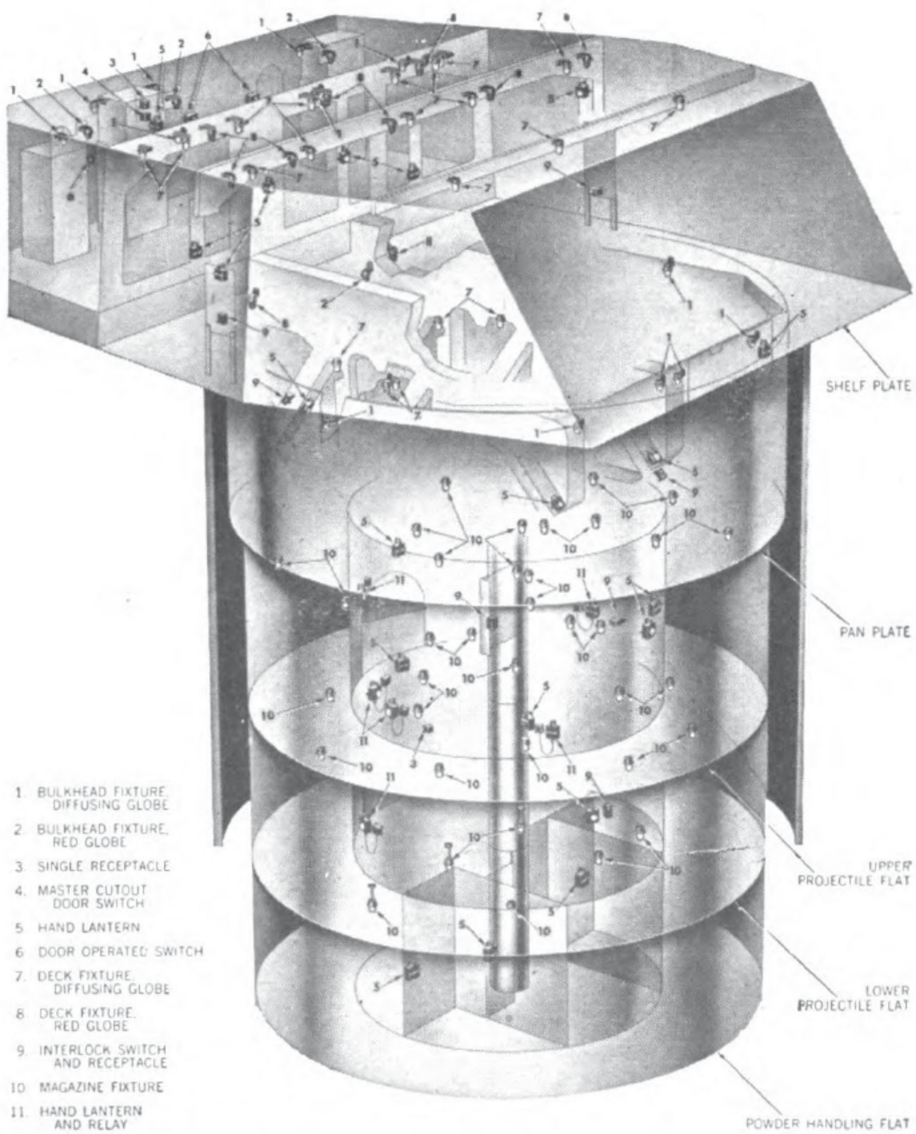


Figure 155.—The turret illumination system indicated by the wiring diagram in figure 154.

in figure 154. What this diagram means is illustrated in figure 155.

Elementary and isometric presentations of a circuit often are on the same blueprint. Isometric wiring drawings never are drawn to any one set scale. The isometric wiring drawing uses schematic symbols.

A cable, regardless of number of conductors, is represented on an isometric wiring diagram by a single line, and no attempt is made to show the proper connections in connection boxes or at fixtures. An isometric type of drawing thus

shows at a glance a rough picture of the entire circuit's layout. Isometric wiring diagrams of lighting and power circuits usually are used to indicate only the main supply cables, feeders, and their associated equipment.

WIRING DECK PLANS

The WIRING DECK PLAN is a blueprint used chiefly in construction. It enables the Navy Yard electrician to lay out his work for a number of cables without referring to each individual isometric wiring drawing. Wiring deck plans do not distort the athwartship members, but represent a true plan.

LIGHTING and POWER wiring deck plans are the actual installation diagrams for the particular deck illustrated. For these systems, the print includes a bill of material listing all material and equipment required to complete the installation on the deck concerned. Equipment and materials, except cable, are assigned symbol numbers and are so indicated on the drawing and in the bill of materials.

Lighting and power circuits, in alternating current work, have indicated at each single-phase fixture, fitting, or appliance the phase to which it is to be connected, such as: AB PHASE, BC PHASE, or CA PHASE. Equipment not so indicated is three-phase.

INTERIOR COMMUNICATION and similar type wiring deck plans are informative plans only, and are merely a composite of all like systems. For these systems, a list of symbols replaces the bill of materials. Symbols and symbol numbers are shown on the plan, but unlike the isometric the section leads of the cables are not indicated.

Wiring deck plans always are drawn to the scale of ¼ inch equals 1 foot. This drawing, therefore, shows an accurate location of all fixtures. The deck plan shows from 150 to 200 feet of deck space on one deck only. A ship 500 feet long at the main deck would require three wiring deck plan blueprints for each system on the main deck. This type of blueprint, like the isometric, uses schematic symbols.

On a small ship a wiring deck plan may cover more than

one electrical system. One wiring deck plan may cover the power, lighting, and IC systems.

TROUBLE SHOOTING BY USE OF BLUEPRINTS

The real value of any knowledge is determined by whether or not a man can use what he knows in practical application. The proper use of blueprints in isolating electrical troubles pays dividends in many ways. It eliminates much of the guesswork in locating trouble in a faulty electrical circuit. Blueprints will save many man-hours spent "sight traveling" a cable along the overhead, down the bulkhead, and through the decks, trying to arrive at its termination at some questionable point.

As a simple example—in isolating trouble in a circuit, assume an electrician is taking insulation tests on a circuit fed from the "FWD" lighting main switchboard. His "Megger" registers zero resistance on the circuit. Since he is not familiar with the location of the various components of this circuit he heads for the log room to draw out the isometric wiring diagrams and elementary wiring diagram of this circuit. At this time he asks the officer of the deck to pass the word that some lights in the forward area of the ship will be off for a short time.

By looking at the isometric of the circuit he locates all the connection boxes. From here on he starts a progressive break-down of the circuit. The logical steps would be:

1. In the first connection box after leaving the switchboard, break all connections.
2. Read each section of the circuit emanating from the box with the megger.
3. After locating the section grounded, remake all connections in the box, close the box, and move along the grounded cable to the next connection box or fixture.
4. Repeat steps 2 and 3 along the line until the ground is isolated to one individual fixture or section of cable.

When the work is completed care should be taken that all covers are properly replaced and secured and the blueprint is again stored in its proper position in the files.

QUIZ

1. Complete the following statements:
   (a) To produce a blue print you project a strong light through the tracing onto a ______ paper.
   (b) Proper care and use of blueprints requires that they:
      1. Be kept out of strong ______.
      2. Are not allowed to get ______.
      3. Be marked, when necessary, with a ______ pencil.
2. Complete the following statements:
   (a) Each Bureau of Ships electrical drawing is designated by numbers and letters grouped in three blocks, of which
      1. The left-hand block indicates the ship ______ and the number of the ship in that ______.
      2. The center block indicates the ______ in which the circuit is classified.
      3. The right hand block gives the drawing's file number within the ______.
   (b) To find which S-group a circuit is classified under, you look it up in the ______ ______ ______.
   (c) Each BuShips print of a circuit or piece of equipment on board ship will have an ______, ______, and ______ number on it.
   (d) Drawings of electrical equipment in turrets or mounts are issued by Bureau of ______.
   (e) Turret or mount electrical drawings are identified by:
      1. ______ number.
      2. ______ designation of the mount or turret.
3. Complete the following statements:
   (a) In a blue print of an object:
      1. Visible object lines are shown by heavy ______ lines.
      2. Dimension lines are shown by ______ solid lines.
      3. Invisible object lines are shown by heavy ______ lines.
      4. Center lines of holes or shafts are shown by alternate and ______ lines.

4. Complete the following statements:
   (a) In electrical wiring diagrams:
      1. ------ symbols are used to show each conductor and all connections.
      2. ------ symbols are used to show location and layout of circuit.
      3. ------ symbols specify watertightness.
      4. Watertightness is shown on the symbols by a ------ line.
   (b) An orthographic view shows an object as seen ------ to your line of vision.
   (c) An orthographic drawing should show as many views of the object as are necessary to give a ------ description of the object.
   (d) The orthographic views of an object should be grouped on the drawing in the same ------ positions they have on the object.
   (e) In preparing an orthographic drawing:
      1. Decide right ------ of views.
      2. Block in ------ of views.
      3. Build up ------ of each view.
      4. Give each view its proper name and ------.
      5. ------ drawing.
   (f) The scale of a drawing refers to size of the drawing relative to ------ ------ of the object.

5. Complete the following statements:
   (a) A drawing in which the object is shown exactly as it appears to the eye is called a ------.
   (b) An isometric drawing shows an object in ------ dimensions.
   (c) In an isometric drawing the vertical edges of the object are shown by ------ lines, its horizontal edges by lines drawn at ------ to the horizontal.

6. Complete the following statements:
   (a) Decks are named and numbered according to their location above or below the ------ deck.
   (b) A partial deck between two full decks is called a ------.

(c) A partial deck below the lowest complete deck is called a ______.

(d) Decks are numbered using the ______ deck as reference level.

(e) A letter ______ precedes the number to denote a half-deck.

7. Complete the following statements:

(a) Ships are divided into sections by bulkheads ______ the ship.

(b) Sections are labeled A, B, C, D, from ______ to ______.

(c) Compartments are the space divisions within ______.

(d) Compartments are designated by:

1. numbers to indicate ______.
2. letters to indicate ______.

(e) All compartments markings consist of three groups of numbers and letters, of which:

1. The first group indicates the ______ of the ship the compartment is in.
2. The second group indicates, in order: (1) ______ level, (2) ______ of ship compartment is on; (3) ______ or ______ position of compartment in the section.
3. The third group indicates the ______ of the compartment.

8. Give the uses of compartments designated by the following symbols:

Symbol	Compartment use
B	
C	
E	
F	
M	

9. Complete the following statements:

(a) Compartments extending through 2 decks are designated by a number after the ______ letter.

(b) Each piece of machinery is designated by three groups of numbers of which:

1. The first group indicates the ______.

2. The second groups indicates the ______.
3. The third group indicates ______ or ______ position.

10. Complete the following statements:
(a) The machinery installation in a mount or turret for a particular job is called an ______ assembly.
(b) Each such assembly is indicated by:
1. A ______ indicating the job it does.
2. A ______ and ______ number to indicate the particular design of such assembly.
(c) The assembly to which each piece of electrical equipment belongs is indicated on its ______.
(d) To find the drawing for a piece of electrical equipment in a mount or turret, first find out what ordnance ______ it is part of.
(e) Drawings of electrical equipment which is part of an ordnance assembly should be obtained from the ______ or ______.

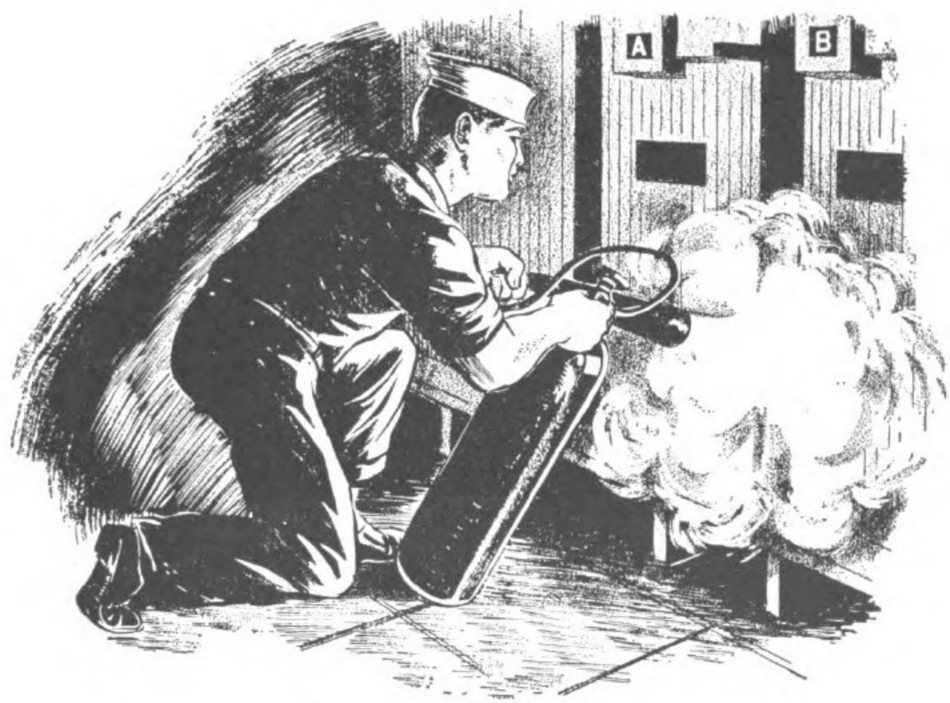
11. Complete the following statements:
(a) Elementary wiring diagrams are used to:
1. Check ______ in a circuit.
2. Make initial ______.
(b) An isometric wiring diagram shows a circuit's ______.
(c) To show location of an electrical system on different decks, isometric wiring diagrams show the decks arranged in ______.
(d) Isometric wiring diagrams show section-, division-, and compartment ______.
(e) Isometric wiring diagrams identify cables by ______ and ______.
(f) Wiring deck plans:
1. Show ______ deck position of cables and equipment.
2. Are used for ______.
3. In case of power and lighting systems, include a list of ______ and ______.
4. Are always drawn to a scale of ¼ inch equals ______.
5. Show one or more ______ on one drawing.

12. How do electrical wiring diagrams save time in troube-shooting?

13. Complete the following statements:

(a) The circuit breaker to a particular load trips open. A check of the load circuit at the switchboard shows a ground in the circuit. You locate the ground by the following steps in the order given:

1. Break out ------ and ------ wiring diagrams for the load circuit.
2. Disconnect ------ power from the load circuit.
3. Open junction box of load circuit nearest ------, break all connections, check all circuits emanating from a box for grounds with megger.
4. After locating grounded branch, ------ all connections in box and replace box cover.
5. Move along grounded cable to next connection box, repeat steps ------ and ------ above.
6. Repeat steps ------, ------, and ------ above until faulty cable fixture or electrical machine is located.



CHAPTER 17

SAFETY PRECAUTIONS

IT PAYS TO PLAY SAFE

Navy electrical equipment is designed and installed with every possible provision for the safety of the men who use it and service it. But this does not completely prevent injury to you and your shipmates or damage to equipment. Safety also depends on the Electrician's Mate. To insure safety while standing watch or working on a circuit, he must always work safely and observe safety precautions. Men have been burned, electrocuted, or maimed for life because they became careless in their work or failed to observe safety precautions.

You were selected to be an Electrician's Mate because of your intelligence, so use your brain to prevent accidents. Injury and damage can be avoided by staying alert, exercising intelligence, and by taking care to work safely. And above all—OBSERVE SAFETY PRECAUTIONS AT ALL TIMES. Violations of safety precautions are the greatest causes of accidents and should be reported and punished as an offense.

Some special safety precautions necessary while standing watch are given in chapter 8; for special precautions necessary while servicing electrical gear see chapter 10; and for precautions in servicing batteries see chapter 13. These and all other precautions necessary while working on electrical equipment aboard ship are summarized in the paragraphs which follow. LEARN YOUR SAFETY PRECAUTIONS NOW. OBSERVE THEM CAREFULLY.

SAFETY PRECAUTIONS FOR ALL MEN ABOARD SHIP

MINOR SCRATCHES and cuts SHOULD always BE GIVEN FIRST AID, as serious infections can result from a small scratch. Get first aid.

Many accidents are caused by skylarking. HORSEPLAY IS DANGEROUS and cannot be tolerated.

Good men have been lost overboard because they would not take the trouble to use a lifeline and wear a lifejacket. WEAR A LIFELINE around your waist, being sure that the other end is secured to the ship, WHENEVER YOU WORK OVER THE SIDE of the ship or on booms, stern light, bow light, in ship's boats, AND ALOFT.

BEFORE GOING ALOFT to work on blinker lights, on yard arms or rigging, first get permission from the OOD and GET RADIO TRANSMITTER SECURED. PULL the FUSES TO CIRCUITS GOING ALOFT, AND TAG SWITCHES OPEN, fastening the tag securely. Have OD's name on the tag and the words, "DANGER—DO NOT CLOSE THIS SWITCH." TIE your TOOLS TO YOUR BELT with a strong cord, BEFORE GOING ALOFT, so they cannot drop on the heads of men standing on deck below you. A better way may be to put all your tools in a bucket which you hoist up and secure aloft with a line.

REQUEST PERMISSION from the OOD BEFORE OPENING CIRCUITS to ship control and navigation circuits. WHEN ALOFT, TEST CIRCUIT WITH your INSTRUMENTS BEFORE TOUCHING it with tools. Many sailors have been killed by a fall when an electric shock knocked them off a mast, yard-arm, or a stage in dry-dock.

HOISTING A HEAVY WEIGHT

When preparing TO HOIST a heavy motor or other HEAVY MACHINERY, USE a BLOCK AND TACKLE, or a chain fall. Secure the hook well to the overhead, using an I-beam clamp if necessary. Do NOT FASTEN the HOOK TO a CONDENSER, PIPE, or a beam that is not strong enough to support the weight being lifted. Never patch a broken chain with wire, a nut and bolt, or other patch. Get it welded properly. WHEN LIFTING, NEVER let a man GET his HANDS OR BODY UNDER THE WEIGHT.

PREPARATIONS BEFORE GOING TO SEA

BEFORE A SHIP LEAVES FOR SEA, SECURE all LOOSE MACHINERY, spare parts boxes and other loose objects so they cannot fall, slide or roll adrift as the ship rolls and pitches heavily in a storm or heavy sea.

Two hours before ship gets underway, all electrician's mates report to the electric shop and start testing all navigation and ship control circuits. The senior petty officer or chief reports to OOD and to OOW one hour before the ship is to get underway, reporting that all ship control circuits have been tested and are operating properly.

EVEN LOW VOLTAGE MAY BE FATAL

At the outset of any consideration of safety from electric shock, it is imperative to recognize that the resistance of the human body cannot be relied upon to prevent a fatal shock from 115-volt or even lower voltage circuits. Tests made by the National Bureau of Standards show that the resistance of the human body may be as low as 300 ohms under unfavorable conditions such as are encountered on naval vessels, because of the presence of water and perspiration. If 0.1 ampere is enough to cause death, and if the body resistance can be as low as 300 ohms, it follows immediately that 115-volt circuits can supply more than enough current to be fatal. Mute witness to the correctness of this conclusion is furnished by the graves of men who have been killed by 115-volt and even lower voltage circuits. All circuits, even if of only a few volts, are potentially dangerous in that they may give rise to currents that are immediately fatal. The resistance of the body itself cannot be relied upon to provide protection from shock.

PORTABLE TOOL HAZARD

All portable tools should have their metal cases grounded when in use so that if the insulation between the live conductors in the tool and its metal case should fail, the power supply to the tool will not make a circuit through the man using it. The Bureau of Ships has developed grounded plugs and receptacles which automatically make the ground connection when the plug is inserted in the receptacle. Always test a portable tool for insulation resistance between its power leads and the metal case with a megger before plugging it in. Also check for sound ground connection to the metal tool case before using it. About 50 percent of shipboard electrical fatalities result from faulty insulation or grounding of portable tools. Full information on electrical safety precautions, particularly with regard to portable tools, is given in the Bureau of Ships Bulletin of Information No. 29 for 1 January 1948 (NavShips 250–001).

SAFETY PRECAUTIONS AROUND SWITCHBOARDS

The man on watch must be alert. Listen for strange or unusual sounds and smells. Watch for overloads on the generators. Feel motors and generators to learn if they are overheating. When a man is working on a circuit, he may phone the man on watch on the switchboard to open a switch for him. Put a tag on the switch, fastening it securely so it cannot fall off the switch. Tags should be kept at switchboard for this purpose, reading "DANGER—DO NOT CLOSE THIS SWITCH." Sign the name and rate of man working on circuit on the tag. Enter this in log book. WHEN TWO OR MORE MEN ARE WORKING ON different branches of the SAME CIRCUIT, each should put a tag on the switch, with his name on his tag, and the SWITCH MUST NOT BE CLOSED UNTIL ALL the MEN ARE CLEAR. IN CASE OF DOUBT take time to make sure all are clear and it is safe to put power on the circuit BEFORE CLOSING THE SWITCH.

Power to switchboards can come in from more than one source of supply. MAKE SURE ALL SOURCES ARE safely DISCONNECTED BEFORE WORKING ON any SWITCHBOARD. Power can come from two or more sources of supply to the shore connection cable, to the distribution and generator switch-

board bus bars, the emergency generator switchboard, the steering engine switchboard, and to other vital equipment. Some have automatic transfer switches, others have manual transfer switches which can be operated to put power on the board from an alternate source of electric power. BE SURE that ALL possible SOURCES OF POWER ARE CUT OFF, BEFORE WORKING ON EQUIPMENT.

The EMERGENCY GENERATOR SWITCHBOARD IS ENERGIZED even THOUGH the DIESEL generator IS NOT RUNNING, because it receives power from the main generators. MEN HAVE BEEN ELECTROCUTED when they touched the emergency generator switchboard bus bars, BECAUSE THEY TOOK IT FOR GRANTED THAT THE EMERGENCY BOARD WAS DEAD WHEN they saw that the DIESEL generator WAS NOT RUNNING. It wasn't, but they are.

In switchboard rooms and other electrical installations, the VENTILATION BLOWERS SHOULD NOT BE AIMED AT or toward the EQUIPMENT. Turn the blower onto the walk. If the blower is trained toward the equipment or switchboard, water from the blower would spray on the equipment and cause a short circuit or possibly electrocute the man on watch.

NEVER GO BEHIND the SWITCHBOARD UNLESS another MAN IS STANDING BY, looking out for you. IF a MAN apparently IS ELECTROCUTED, OPEN SWITCH BEFORE TOUCHING HIM yourself. Use rubber gloves or other insulated protection; then pull him clear quickly, and IMMEDIATELY ADMINISTER ARTIFICIAL RESPIRATION to the victim.

ARTIFICIAL RESPIRATION must be started immediately, the same as to an apparently drowned man, and MUST BE KEPT UP FOR 4 HOURS or until rigor mortis sets in, unless the doctor says there is no further use. Men have been resuscitated by this method several hours after a shock, so do not give up hope.

SAFETY PRECAUTIONS SHOULD BE POSTED in all shops, on switchboards, and in the storage battery charging locker.

Take great care to prevent water from getting into switchboards, panels, storage batteries and other electrical equipment, and to keep loose tools from falling on or into

them, that can cause a short-circuit and a great deal of damage as well as danger to personnel. Do NOT CARRY METAL tools, rulers, or other metal OBJECTS IN your SHIRT POCKET, as they can fall into machinery or switchboards when you lean over machinery. The resulting short circuit usually severely burns the man involved.

SAFETY PRECAUTIONS IN THE USE OF TOOLS

Always WEAR GOGGLES WHILE GRINDING on a tool grinder, while chipping, and while watching others grind or chip. People who ignored this warning are wearing a glass eye today because they were too lazy to put on goggles.

TAPING the HANDLES of tools with friction tape may give you a better grip on them, but DOES NOT MAKE the TOOL SHOCK-PROOF. They are NOT SAFE to work with ON a HOT CIRCUIT. One hole in the tape, is enough to electrocute or burn a man.

DON'T STICK a BARE screwdriver or other TOOL INTO a HOT FUSE BOX.

WHEN DRILLING a hole, DON'T attempt to HOLD the STOCK IN your HAND—either chuck it in a bed vise, or clamp it with C-clamps, or hold it with vise-grip pliers. GET the RIGHT TOOL FOR the JOB—even if you have to return to shop for it. Never use a screwdriver to pry with. Use a pry bar or a crow bar. Never use a screwdriver for a chisel, or hammer on it. Never use a wrench for a hammer. NEVER HAMMER on end-bell or other CASTING WITH a BALLPEEN HAMMER. Use a mallet or a hide faced hammer. NEVER LEAVE a SOLDERING IRON PLUGGED IN WHEN NOT IN USE. It will burn up the iron, and may start a fire. Place soldering iron in the rack when not in use.

Return tools to your shop when finished with them, as someone else may be waiting to use them. A good motto for your shop is, "A PLACE FOR EVERYTHING—EVERYTHING IN ITS PLACE."

STORAGE BATTERY SAFETY PRECAUTIONS

Storage batteries give off an explosive gas while being charged, and a cigarette, a flame or a spark can cause a

disastrous explosion. "NO SMOKING" regulations MUST BE ENFORCED strictly WHILE BATTERIES ARE CHARGING. Always keep connections clean and tight, to prevent arcing that may cause explosion. Never let battery temperature get above 125° F.

Storage batteries use strong chemicals as electrolytes, so TAKE GREAT CARE TO AVOID ELECTROLYTE LEAKING OR SPILLING, TO PREVENT BURNING personnel or damaging equipment.

In mixing electrolyte, use only acid resisting, non-metallic vessel (stone or glass). POUR ACID INTO WATER, NEVER WATER INTO ACID, because explosion may result. Be careful not to spill, to avoid burns.

RUBBER GLOVES

Rubber gloves will be ruined by heat, sunlight, or pressure. Stow them in a box where temperature will not exceed 90° F.

Figure 156.—Rubber gloves and leather glove protectors.

Gloves should not be flattened, folded, or turned inside out. They should be kept free from oil, grease and water. Wash with castile soap in lukewarm water, rinse in cool clear water, before stowing the gloves.

Always wear protectors (leather gloves) over the rubber gloves while working. Before a rubber glove is used, it should be tested for holes. To test, fill glove with air by twirling it with the cuff rolled. It should then be squeezed. If the glove has a hole, air will leak out.

SAFETY PRECAUTIONS WHILE WORKING ON CIRCUITS OR EQUIPMENT

MEN HAVE LOST FINGERS OR HANDS, cut off by running machinery BECAUSE SOMEONE CLOSED a SWITCH WITHOUT MAKING SURE IT WAS SAFE TO turn it on and RUN THE MACHINE. This is especially dangerous around pumps, blowers, ammunition hoists, elevators, rams, and galley and carpenter shop equipment.

COVERS OR screen GUARDS SHOULD BE INSTALLED TO PROTECT personnel FROM injury or shock from EXPOSED GEARS, CHAINS, AND BARE ELECTRIC CONDUCTORS such as third rails, trolleys, collector rings, brushes, and other electrical installation that is not insulated, or which is mechanically dangerous.

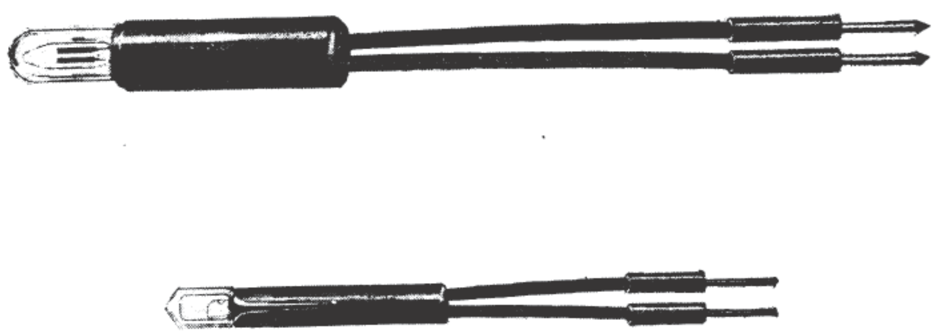


Figure 157.—Test lights.

Always ASSUME that a CIRCUIT is NOT SAFE UNTIL you are SURE that IT IS DEAD—and MAKE SURE that IT WILL NOT BE ENERGIZED AFTER YOU START WORKING ON IT. USE A VOLTAGE TESTER on circuit. TEST from EACH LEAD to ground, AS WELL AS BETWEEN LEADS. Any man who tests for 440 volts with his fingers will do so but once.

Always USE FUSE PULLERS, figure 158, TO CHANGE A FUSE, never fingers, pliers or screwdriver.

ALL METAL connection BOXES, switch boxes, starting boxes, transformer shells, AND motor FRAMES SHOULD BE GROUNDED to the hull or to water pipes, to prevent shock to personnel. This is ESPECIALLY important in PORTABLE drills and other portable ELECTRIC POWER TOOLS, AND SUBMERSIBLE PUMPS.

Figure 158.—Fuse pullers.

Take insulation tests frequently with megger or vibrotester, and test for grounded frame when you test insulation resistance. BE OBSERVANT! Fix or report at once anything you see that is damaged or needs repairing. Replace missing screws, and rotten or missing gaskets, at once. A stitch in time saves nine, in this business.

WHEN USING a PORTABLE electric METER, DON'T connect only one wire and LEAVE other WIRE dangling about LOOSE. Anyone touching it will receive a shock through the meter.

GASOLINE OR BENZINE SHOULD NOT BE USED on or near running machinery, or in an enclosed space, or below decks.

INFLAMMABLE VAPORS are invisible, but spread and flow along the deck and down open hatches. They become ignited and SPREAD the FLAME the instant a spark is struck. If necessary TO USE an INFLAMMABLE SOLVENT to clean a motor or parts, first POST a GUARD, ENFORCE SMOKING REGULATIONS, and TAKE CARE that a SPARK IS NOT STRUCK by a tool striking steel.

CONCLUSION

ALWAYS PULL FUSES FIRST, OR DISCONNECT LEADS IN POWER PANEL, BEFORE WORKING ON A CIRCUIT. Test a circuit with your neon test light or voltage tester before working on it—ALWAYS ASSUME THAT IT IS HOT UNTIL YOU ARE SURE. MAKE SURE THAT IT CANNOT BE ENERGIZED WHILE YOU ARE WORKING ON IT.

DON'T THROW POWER ON TO A CIRCUIT UNTIL YOU FIRST MAKE SURE that ALL ARE CLEAR. Ask the petty officer or responsible man on that station if motor is free to run, before you start it. This is necessary to prevent injury to men and machinery.

AVOID ACCIDENTAL CONTACT WITH EQUIPMENT OR CONDUCTORS WHICH ARE KNOWN TO BE ALIVE OR ARE NOT KNOWN TO BE DEAD. If it is necessary to work on equipment while it is hot, extra care must be observed. See chapter 60 of the Bureau of Ships Manual for the precautions to be observed in this case.

ALWAYS TEST EQUIPMENT FOR INSULATION RESISTANCE AND INTEGRITY OF GROUND CONNECTION BEFORE USING IT FOR THE FIRST TIME AND BEFORE TESTING IT OUT FOR OPERABILITY FOR THE FIRST TIME AFTER IT IS RECEIVED AND AFTER ANY REPAIR WORK IS DONE ON IT.

ALWAYS TEST OUT AND REPAIR EQUIPMENT WHICH GIVES A WARNING OF UNSAFE CONDITION BY GIVING A NONFATAL SHOCK. Remember that electricity frequently kills without warning and that when a warning is given, it is a piece of good fortune which it is almost criminal to disregard. Never assume that because the warning shock is nonfatal, the next shock will also be nonfatal. Experience in the Navy within the past few years shows beyond all doubt that this assumption is wrong.

TAKE TIME TO BE CAREFUL! Your careful work, observation of safety precautions, and a little thoughtfulness will prevent injury, mutilation or death to your shipmates and to yourself.

QUIZ

1. Complete the following statements:
   (a) Always wear a ------ when working over the side or aloft.
   (b) Before going aloft, secure and pull ------ of all circuits going aloft.
   (c) When lifting heavy machinery, never get ------ the weight.
   (d) Before ship leaves for sea, secure all ------ machinery.
   (e) When two or more men work on the same circuit, insure all men are clear before ------ circuit switch.
   (f) Before working on any switchboard, insure ------ sources of power to board are shut off.
   (g) Never go behind switchboard unless another man is ------------.
   (h) In case person is electrocuted:
      1. First ------ circuit switch before touching him.
      2. Remove him to adequate space and apply artificial respiration ------.
      3. Continue artificial respiration for at least four ------.
   (i) When working on machinery, do not carry tools in shirt ------.
   (j) Wear ------ when grinding.
   (k) Smoking must not be allowed where batteries are ------.
   (l) Take care to avoid spilling battery ------.
   (m) To mix battery electrolyte, always pour acid into ------.
   (n) Be sure no one is working on circuit, and all persons are clear of circuit machinery, before turning on ------.
   (o) Use voltage testers to check if circuit is ------.
   (p) When using inflammable solvents for cleaning, insure there is no smoking, no sparks from tools, in space where solvent ------ may spread to.

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 1

ELECTRICAL CURRENTS AND CIRCUITS—OHM'S LAW

1. volt
2. ampere
3. ohm
4. (a) directly
   (b) inversely
5. volts/ohms
6. 6 ohms
7. 12 amperes
8. 60 volts
9. (a) $I=6$ amperes
   (b) $R_t=20$ ohms
   (c) $R_x=4$ ohms
10. (a) $I=10$ amperes
    (b) $I=10$ amperes
11. $I=10$ amperes
12. (a) $I_{R7}=14.28$
    $I_{R2}=50.00$
    $I_{R1}=100.00$
    (*b*) $I_T=164.28$ amperes
    (c) $R_T=\dfrac{100}{164.3}=.608$ ohm
13. $E=40$ volts
14. $R=20$ ohms
15. (a) $I_T=72$ amperes
    (b) $P_T=8640$ watts
    (c) $P_{R12}=1200$ watts
    $P_{R4}=3600$ watts
    $P_{I12}=1440$ watts
    $P_{I20}=2400$ watts
16. (a) $R_x=30$ ohms
    (b) $P_x=750$ watts
    $P_{50}=450$ watts
    $P_{75}=300$ watts
    (c) $P_T=1500$ watts
17. $R_x=120$ ohms
18. $R_x=75$ ohms
19. $R_x=11.80$ ohms
20. $R=12$ ohms
21. $E=80$ volts
22. $P=1300$ watts
23. Across 2-lamp group,
    $E=116$ volts
    Across 3-lamp group,
    $E=113$ volts
24. (a) heat
    (b) resistance
    (c) current
    (d) great
25. Overheating chars and breaks down the insulation

CHAPTER 2

MAGNETISM

1. Steel, nickel, cobalt, chromium
2. Magnetic alloys—alonico, permalloy, perminvar
3. Air, copper, rubber, wood
4. Nonmagnetic materials do not insulate electric flux as electric insulators insulate electric current
5. (a) Stroke with magnet
   (b) Place next to magnet
6. (a) force
   (b) field
   (c) flux
   (d) circuit
7. (a) strength
   (b) lines
   (c) gauss
8. (a) shorten
   (b) all
   (c) easily
   (d) push, apart
   (e) cross
   (f) loop
   (g) repel
   (h) attract
   (i) directly
   (j) inversely
9. In a magnetic material the electrons of each atom have their orbits in the same plane, in nonmagnetic materials they do not
10. It arranges them so their magnetic axes are parallel
11. Because there is more frictional resistance to magnetic alignment of the molecules in steel than in iron
12. Weaken its field
13. Move one end of compass near the material; move compass away; move other end of compass near the material. If material attracts both ends of compass it is not magnetized

CHAPTER 3

ELECTROMAGNETISM AND MAGNETIC CIRCUITS

1. By observing the motion of a compass needle when brought near the current—carrying conductor
2. Circular field concentric with the conductor
3. Reverses the field
4. Current, field
5. Decreases with distance from the conductor
6. (a) add
   (b) repulsion
   (c) cancel
   (d) attraction

7. Circular loop
8. Solenoid
9. At the center
10. Field, current
11. (a) flux
    (b) attracted
12. 1. Magnetic brake; 2. magnetically operated circuit breakers; 3 solenoid—operated valves
13. (a) electromagnet
    (b) circuit
14. (a) flux
    (b) greater
    (c) greater
    (d) 1. increase
        2. increase
    (e) ampere-turns
    (f) gilbert
15. reluctance
16. permeability
17. (a) directly
    (b) inversely
    (c) magnetomotive force reluctance
18. (a) saturation
    (b) retentivity
    (c) hysteresis
    (d) heat

CHAPTER 4

INDUCTION

1. Michael Faraday
2. (a) induced
   (b) greater
       reverses
       zero
   (c) motion
3. (a) 1. flux
       2. motion
       3. the induced emf
   (b) 1. motion
       2. flux
   (c) current
4. (a) greater
   (b) volt
   (c) speed
       field
       turns
5. (a) changing
   (b) primary
       2. secondary
   (c) induction
   (d) generator
   (e) field
   (f) generators
   (g) transformers
6. field
   (a) oppose
   (b) harder
8. (a) self
   (b) changes
   (c) oppose
   (d) aid
   (e) opposes
9. opened
10. opened

CHAPTER 5

ALTERNATING- AND DIRECT-CURRENT GENERATORS

1. (a) across
   (b) along
2. (a) opposite
   (b) sine
   (c) cycle
   (d) cycles
   (e) frequency
3. (a) armature
   (b) stator
   (c) slip rings
   (d) commutator
   (e) reverses
   (f) direct
4. (a) rectification
   (b) twice
   (c) ripple
   (d) increased
5. (a) increase
   (b) increase
   (c) increase
   (d) decrease

CHAPTER 6

DIRECT-CURRENT GENERATORS

1. Prime mover
2. To support the field poles
3. By current in the field pole windings
4. Alternating polarity
5. Armature coils are inserted in armature slots and held in slots by wooden wedges
6. (1) Copper segments
   (2) Mica
   (3) Clamping flanges. All are held in place on shaft by bolting clamping rings to shaft
7. Brushes provide electrical connection between armature coil turns and external circuit
8. (1) Brush—provides electrical connection between commutator segment and external circuit
   (2) Brush holder—keeps brush in contact with commutator
   (3) Brush yoke—permits shifting brush position to neutral plane

9. (a) opposite
   (b) pitch
   (c) pitch
   (d) $\dfrac{\text{number of armature slots}}{\text{number of field poles}}$
10. 7
11. (a) lap
    (b) wave
    (c) front pitch
    (d) back pitch
12. As many segments as there are coils are required in the commutator for a lap or a wave winding

CHAPTER 7

TYPES OF DIRECT-CURRENT GENERATORS

1. (a) characteristic
   (b) downward
   (c) exciter
2. Automatic control systems
3. Shunt, series, compound
4. Armature
5. (a) in series with
   (b) in parallel
   (c) in series with, in parallel with
6. To draw only small part of output current from generator
7. Because series field adds voltage drop in series with load, and this drop must be kept small
8. (a) residual magnetism
   (b) increases
   (c) 1. too little
       2. too much
       3. reversed
       4. open

(d) constant
(e) saturated
(f) resistance
(g) regulation
(h) percent
(i) $\frac{\text{(no-load voltage)—(full load-voltage)} \times 100}{\text{full-load voltage}}$
(j) 1. dims
2. slows

9. 4.35%

10. (a) cumulatively
(b) differentially
(c) flat
(d) over
(e) under
(f) resistance
(g) diverter
(h) $\frac{\text{(full-load voltage)—(no-load voltage)} \times 100}{\text{no-load voltage}}$

11. 4.35%

12. (a) resistance
(b) midway
(c) half
(d) full
(e) reduces
(f) no
(g) neutral
(h) copper
(i) excessive

13. (a) neutral
(b) armature
(c) rotation
(d) neutral
(e) current
(f) position
(g) interpose
(h) armature
(i) poles

CHAPTER 8

OPERATION OF DIRECT-CURRENT GENERATORS

1. (a) Switchboard
   (b) battle
2. Big generator would carry only small part of full load most of time, would be inefficient at low output
3. (a) sum
   (b) each
   (c) added to
   (d) removed from
   (e) same
   (f) voltage
4. (a) When shifting from shore to ship power
   (b) When there is total loss of power from generators
5. Listed under "Energizing a Dead Switchboard." Ch. 8
6. Listed under "Energizing a Dead Switchboard" Ch. 8
7. Listed under "Paralleling D–C Shunt Generators," Ch. 8
8. Listed under "Securing D. C. Generators", Ch. 8
9. May get sudden reversal of generator by current inrush from bus
10. Listed under De-energizing of Switchboards, Ch. 8
11. To prevent runaway shift of load off one generator onto other
12. (a) series
    (b) unequal
    (c) 1. decrease
        2. increase
    (d) 1. full line
        2. no
13. Entire line load falls on one generator, overload trips its breaker, cuts off entire ship's power supply
14. Listed under "Paralleling Compound Generators", Ch. 8
15. Listed under "Securing D-C Compound Generators", Ch. 8
16. The same except that you have to connect two equalizers instead of one
17. Listed under "Safety Precautions for General Watch Standers", Ch. 8
18. Listed under "Duties of a Watch Stander," Ch. 8

CHAPTER 9

DIRECT-CURRENT MOTORS

1. (a) motor
   (b) motor
2. Motors are more fully enclosed, have a fan for air cooling
3. (a) force
   (b) across
   (c) capacity
   (d) 1. flux
       2. current
       3. length
   (e) $\dfrac{K \text{ (constant of design)} \times Ia \text{ (armature current)}}{\Phi \text{ (field flux)}}$
4. (a) 1. flux
       2. current
       3. motion
5. (a) counter
   (b) opposes
   (c) 1. speed
       2. strength
   (d) K (design constant)$\times\Phi$ (field flux)$\times S$ (speed)
   (e) Ia (armature current)$\times Ra$ (armature resistance)
   (f) counter electro-motive force
   (g) current
6. (a) resistances
   (b) resistances
   (c) starter, controller
   (d) load
   (e) smaller
   (f) line voltage

7. (a) 1. load
   2. flux
   3. voltage
   (b) $\dfrac{E_L \text{ (line voltage)} - \mathit{IaRa} \text{ (armature resistance drop)}}{K \text{ (design constant)} \times \Phi \text{ (field flux)}}$
8. 1,050 revolutions per minute (rpm)
9. (a) current
   (b) speed
   (c) foot-pounds
   (d) speed
   (e) $\dfrac{\text{output}}{\text{input}}$
   (f) 746
10. (a) 2300
    (b) 3.109
    (c) 2.47
11. Series, shunt, compound
12. Cumulative and differential
13. (a) characteristic
    (b) increases
    (c) excessive
    (d) across
    (e) constant
    (f) field, armature current

CHAPTER 10

MAINTENANCE OF DIRECT-CURRENT MOTORS AND GENERATORS

1. (a) 1. vibration
   2. metallic
   3. moisture
   (b) film
   (c) races
   (d) foreign matter and friction
   (e) oilite
2. (a) soap
   (b) vegetable
   (c) right
   (d) over
   (e) dust

3. (a) disconnect
(b) chocolate
(c) fine sandpaper
(d) stone
(e) groove
(f) blown out
(g) up, down
(h) 1½–2
(i) sparking
(j) brush wear

4. (a) 1. location
2. positioned
3. poor
4. rough
5. copper
6. bars
7. shorted
8. excessive

5. (a) cumulative
(b) megger
(c) heat
(d) 150
(e) rated
(f) insulation
(g) carbon tetrachloride
(h) confined

6. (a) daily
(b) week
(c) quarterly
(d) quarterly
(e) 1. disconnect
2. switchboards

7. (a) disconnect
(b) warning sign
(c) shorted
(d) experience
(e) instructions

8. 1. 11F, 11G
2. 13E
3. 20
4. 24
5. 27–30; 33
6. 34; 41
7. 44C
8. 47; 51; 52
9. 53B, 54; 55; 56
10. 58A, 58C
11. 59; 60; 61; 62

CHAPTER 11
DIRECT-CURRENT CONTROLLERS

1. (a) 1. changing
2. reversing
(b) 1. overloaded
2. foils
(c) manually
(d) automatically
(e) stationary
(f) fingers
(g) 1. live
2. arcs
3. damage
(h) shock-resistance
(i) 1. L_1, L_2
2. A_1, A_2
3. V_1, V_2

2. (a) small
(b) electromagnet
(c) disconnects
(d) racing

3. (a) frequent
(b) reverses
(c) 1. coils 2. arc

4. (a) automatic
   (b) 1. distant
       2. several
   (c) holding
5. Open line switch, remove overload, reclose line switch
6. (a) fully automatic
   (b) semiautomatic
   (c) non-automatic
7. (a) faster
   (b) solenoids
   (c) burning
   (d) 1. voltage
       2. current
8. (a) field coil
   (b) trouble
   (c) close
   (d) leakage paths
   (e) 1. ¼
       2. full
       3. megohm
9. (a) tight
   (b) $\frac{1}{16}$
   (c) gunfire
   (d) disconnect
   (e) 1. inflammable
       2. insulation resistance
   (f) higher
   (g) higher

CHAPTER 12

CABLES

1. (a) strands
   (b) multiconductor
2. 1. Rubber insulated, fixed
   2. Rubber insulated, flexible
   3. Varnished cambric
   4. Heat and flame resistant
   5. Silk, cotton, and enameled
3. 1. Number
   2. Type
   3. Type
   4. Size
4. Triplex, oil resistant, portable 4,000 c. m.
   Duplex, heat and flame reristant, armored, 14,000 c. m.
5. Triplex, oil resistant, portable, 4,000 c. m.
   Duplex, heat and flame resistant, armored, 14,000 c. m.
   Multiple, heat and flame resistant, armored, 3,000 c. m.
   Four conductor, oil resistant, portable 9,000 c. m.
6. (a) 5
   (b) 1. amperes
       2. length
       3. allowable

(c) $\dfrac{10.8 \times \text{length} \times \text{current}}{\text{E (allowable drop)}}$

7. 940 circular miles
8. 940 circular mils
9. (a) junction boxes
   (b) stuffing tubes
   (c) terminal boards
   (d) ordnance
   (e) ordnance pamphlets
   (f) gunnery
10. See list in chapter 12

CHAPTER 13

BATTERIES

1. Primary cells generate electricity, cannot be recharged, secondary cells store electricity and can be recharged.
2. (a) 1. negative
       2. positive
   (b) removed
   (c) voltmeter
   (d) hydrometer
   (e) sulphuric acid
3. To release gasses generated by its chemical action.
4. By baffle plates placed inside the vent
5. (a) 2.0
   (b) ampere-hour
   (c) current $\times$ amperes
6. 5 hours
7. 50 ampere-hours
8. (a) 1. lead sulphate
       2. water
   (b) acid
   (c) specific gravity
   (d) 1.300
   (e) 0.001
   (f) freeze
   (g) 1. 1.210–1.220
       2. 1.060
9. (a) self-discharge
   (b) 1. A short circuit
       2. acid
   (c) buckle
   (d) plates
   (e) 1. vent plugs
       2. electrolyte
       3. two
10. Hydrogen gas, given off during charging, forms explosive mixture with oxygen in the air
11. At higher temperatures plates buckle
12. Metal
13. If water is poured into acid explosion results
14. Acid will burn hands, eat away anything spilled on
15. Send to nearest naval shipyard for chemical test.

CHAPTER 14

ELECTRICAL SYSTEMS IN SMALL CRAFT

1. Mixture of salt water with electrolyte
   - (1) ruins the plates
   - (2) generates poisonous fumes
2. See answer to question 15 of Quiz for chapter 13
3. Starter draws a very heavy current which causes harmful chemical changes in the battery
4. (a) series
   (b) grounding
   (c) insulated
   (d) salt water
5. To avoid heavy starter current flow through long leads to starter button.
6. (a) shunt
   (b) field
   (c) voltage
7. To prevent battery current flowing to generator when it is not running
8. (a) overcharging
   (b) resistance
   (c) 16%
9. 1. spark plug
   2. distributor
   3. induction coil
   4. distributor
   5. distributor
10. A hot wire heated electrically to aid cold weather Diesel starting by warming the air mixture
11. 10 minutes

CHAPTER 15

SEARCHLIGHTS

1. (a) reflector
   (b) carbon arc
   (c) incandescent lamp
   (d) fire control
   (e) signalling
   (f) remote control
   (g) 1. flicker
   2. bluish white
   (h) 1. 360
   2. 110
   3. 20 or 40
2. (a) contact
   (b) vapor
   (c) vapor
   (d) focus
3. High intensity have smaller diameter carbons and heavier currents
4. To prevent overheating
5. By slip rings and brushes or by flexible cables

6. (a) 1. drum
2. trunnion arms
3. base
(b) 1. barrel
2. doors
3. ventilation
4. image
(c) 1. column
2. positive head
3. shield
(d) 1. ventilation
2. feed
3. Rotation
4. feed
5. arc
(e) focus
(f) thermostatic
(g) symmetrical
(h) feed
7. (a) parabolic
(b) 1. silver
2. chromium
(c) center out
8. (a) shut off
(b) slow
(c) speed
9. (a) arc
(b) stops
(c) decrease
10. (a) arc
(b) increase
11. (a) angle
(b) 8 to 10
(c) focus
(d) negative
(e) reflector
12. (a) 1. 105
2. 45
(b) 3
(c) stop
(d) 1. chalk, alcohol
2. center out
3. rotary
(e) heads
13. See lists in chapter 15

CHAPTER 16

BLUEPRINT READING AND SKETCHING

1. (a) light-sensitive
(b) 1. sunlight
2. wet
3. yellow
2. (a) 1. class, class
2. S-group
3. S-group
(b) Navy Filing Manual
(c) index, group, file
(d) ordnance
(e) 1. serial 2. BuOrd
3. (a) 1. solid
2. light
3. broken
4. dash, dot
4. (a) 1. Elementary
2. schematic
3. schematic
4. double
(b) perpendicular
(c) complete
(d) relative

(e) 1. combination
2. outlines
3. details
4. dimensions
5. check

(f) actual size

5. (a) perspective
(b) three dimensions
(c) vertical, 30°

6. (a) main
(b) half
(c) platform
(d) main
(e) H

7. (a) across
(b) fore, aft
(c) sections
(d) 1. location 2. use
(e) 1. section
2. 1. deck 2. side
3. fore, aft
3. use

8. Gun and torpedo battery
Ship control and fire control
Machinery
Fuel
Ammunition Storage

9. (a) section
(b) 1. deck level
2. frame
3. port, starboard

10. (a) ordnance
(b) 1. name
2. mark, mod
(c) name plate
(d) assembly
(e) gunnery officer, chief Gunner's Mate

11. (a) 1. connections 2. hook-up
(b) layout
(c) tiers
(d) bulkheads
(e) number, size
(f) 1. exact
2. construction
3. materials, equipment
4. 1 inch
5. systems

12. Save time in tracing circuits

13. 1. elementary, schematic
2. all
3. switchboard
4. remake
5. 3, 4
6. 3, 4, and 5

CHAPTER 17

SAFETY PRECAUTIONS

1. (a) lifeline
   (b) switches
   (c) under
   (d) loose
   (e) closing
   (f) all
   (g) standing by
   (h) 1. open
       2. immediately
       3. hours
   (i) pockets
   (j) goggles
   (k) charging
   (l) electrolyte
   (m) water
   (n) power
   (o) energized
   (p) vapor

APPENDIX II

QUALIFICATIONS FOR ADVANCEMENT IN RATING

ELECTRICIAN'S MATES (EM)

Rating Code No. 500

General Service Rating

Electrician's Mates stand watch on motors, generators, and switchboards. Operate searchlights and other electrical equipment. Maintain and repair power and lighting circuits, fixtures, motors, generators, distribution switchboards, and so forth. Test circuits for shorts, grounds, or other casualties. Administer and perform electrical shop work, which includes rewinding armatures and maintaining storage batteries.

Emergency Service Ratings

Title	Abbr.	Rating Code No.	Definition
Electrician's Mates P--	EMP	501	Operate and maintain heavy and light a-c and d-c power and lighting circuits and equipment abroad naval vessels. Stand watches on generators, switchboards, electric propulsion motors, and control equipment.
Electrician's Mates S--	EMS	502	Repair and rebuild electrical equipment and instruments in electrical shop. May stand watch on switchboard or steering engines.

Naval Job Classifications

Group code numbers	Group titles	General Service, EM	Emergency Service	
			EMP	EMS
37200–37299	Instrument Repairmen	X		X
38300–38399	Electricians, Power and Lighting	X	X	
38600–38699	Electricians, Mine Warfare	X	X	
38900–38999	Electricians, Basic	X	X	X
82100–82199	Motion Picture Projector Operators and Repairmen	X	X	X

Qualifications for advancement in rating	Applicable rates		
	EM 500	EMP 501	EMS 502
.100 Practical Factors			
.101 Tools			
Use all common electrician's tools	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Perform simple soldering and brazing	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Operate small lathes used to turn down commutators on armatures.	2, 1, C		3, 2, 1, C.
.102 Blueprints			
Read and use simple electrical blueprints, wiring diagrams, and designs.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Prepare electrical diagrams and sketches	1, C	1, C	1, C.
.103 Materials			
Identify commonly used electrical materials	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
.104 Electrical Connections			
Splice wire. Solder electrical connections. Splice cable.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Connect electrical power machinery and electrical power equipment, including generators and distribution switchboards.	2, 1, C	2, 1, C	2, 1, C.
.105 Batteries			
Install batteries (wet and dry cell). Make specific-gravity tests and charge storage batteries.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Repair storage batteries	1, C		2, 1, C.
.106 Watches			
Stand watch on ship's service or emergency electrical switchboards.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.

Assume one of the following stations under way: propulsion control board on electric-drive vessel, steering engine; generating equipment.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Serve in charge of all watches in the Electrical Division except gyro and interior communications (I. C.).	1, C	1, C	1, C.
.107 Motors			
Start, stop, clean, and lubricate electric motors	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Perform upkeep on electric motors: wipe commutator or replace and fit brushes.	3, 2, 1, C		3, 2, 1, C.
Assist in winding, insulating, and baking armatures and field coils.	3, 2, 1, C		3, 2, 1, C.
Wind, bake, and insulate armatures and field coils for electric moters.	1, C		1, C.
.108 Generators			
Operate and synchronize generators in parallel	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Assist in servicing, lubricating, and checking generating equipment.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Assist in repairing generating equipment	3, 2, 1, C	2, 1, C	3, 2, 1, C.
Service, lubricate, check, and repair generating equipment.	2, 1, C		2, 1, C.
.109 Transformers			
Maintain and repair current and voltage transformers (if available).	2, 1, C		2, 1, C.
.110 Distribution Panels and Switchboards			
Clean and check distribution panels, switches, and switchboards. Lubricate controllers.	3, 2, 1, C	3, 2, 1, C	
Repair distribution panels and switchboards	2, 1, C		2, 1, C.
Maintain and repair voltage regulators	1, C	1, C	2, 1, C.
.111 Circuits and Wiring			
Repair open circuits; find and clear grounds; run wiring for fans, call bells, lights, etc.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Install or replace any power and lighting circuit aboard ship.	1, C	1, C	

Qualifications for advancement in rating	Applicable rates		
	EM 500	EMP 501	EMS 502
.112 Searchlights			
Operate searchlights on own ship. Perform upkeep	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Make major repairs to searchlights	1, C	1, C	2, 1, C.
.113 Electrical Equipment			
Repair electrical equipment (including the ignition system) of ship's boats.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Repair electrical appliances such as toasters, electric drills, vacuum cleaners, sterilizers, etc.	1, C		2, 1, C.
.114 Tests and Inspections			
Use voltmeter, ammeter, ohmmeter, megger, wattmeter, and circuit analyzer.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Complete all necessary tests of electrical equipment, using standard test equipment, including circuit analyzers. Assist with all major trouble-shooting.	2, 1, C	2, 1, C	2, 1, C.
Make necessary tests and inspections of all shipboard electrical power apparatus.	1, C	1, C	1, C.
.115 Estimates			
Estimate time, materials, and labor required for the repair of electrical equipment.	1, C	1, C	1, C.
.116 Damage Control			
Fight electrical fires, under simulated conditions; serve as electricians in repair parties. Maintain in operations, under emergency conditions, power and lighting circuits; rig for casualty power.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
.117 First Aid			
Simulate the rescue of a person in contact with an energized circuit; resuscitate a person unconscious	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.

from shock (simulated conditions). Simulate treatment for shock and burns.			
.118 Records and Reports			
Maintain all required records, check-off lists, reports, etc., at own station.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Make all records, reports, machinery histories, etc., required in the Electrical Division.	1, C	1, C	1, C.
Prepare requisitions for any materials or equipment required.	1, C	1, C	1, C.
.119 Publications			
Use electrical handbooks for selecting materials and data.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
.120 Supervision			
Supervise and train personnel in general electrical repair work.	1, C	1, C	1, C.
Plan, organize, administer, and direct work of:			
Electrician's Mates P	1, C	1, C	
Electrician's Mates S	1, C		1, C.
.200 Examination Subjects			
.201 Electricity			
Terminology of common terms used in electricity; electron theory; Ohm's law and Kirchhoff's laws; simple problems in alternating current and direct current.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Electrical circuits for all types of devices and equipment, except IC and gyro.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Compute the elements of simple electrical circuits in alternating current and direct current.	2, 1, C	2, 1, C	2, 1, C.
All wiring diagrams, including advantages, characteristics, and uses of Y, Delta, and V connections for transformers. Three-wire and four-wire transmission systems.	2, 1, C	2, 1, C	2, 1, C.

Qualifications for advancement in rating	Applicable rates		
	EM 500	EMP 501	EMS 502
.201 Electricity—Continued			
Electrical theory and its practical shipboard application in motors, generators, transformers, switchboards, control appliances, and other electrical equipment.	2, 1, C	2, 1, C	2, 1, C.
.202 Power Equipment			
Care and stowage of all electrical materials; basic knowledge of all electrical equipment.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Naval shipboard type electrical cable, terminal markings, and designations.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Theory, construction, and characteristics of a-c and d-c motors, controllers, generators, voltage regulators, and current and voltage transformers; Bureau of Ships requirements for care and maintenance of equipment.	3, 2, 1, C	3, 2, 1, C	3, 2, 1, C.
Layout and installation of switchboards and panels, including ship's service switchboards.	1, C	1, C	1, C.
.203 Electrical Propulsion			
Show by diagram the motors and machinery in a typical A. C. electric drive ship and know the theory of electrical propulsion.	2, 1, C	2, A, C	
.204 Vacuum Tubes			
Theory of the vacuum tube and the relations between grid, plate, and filament under various conditions.	1, C	1, C	
.205 Synchro Units			
Theory and operating principles of the various types of synchro units used in interior communications and fire control.	1, C	1, C	1, C.

.206 Gyroscope			
Theory of the gyroscope	1, C.	1, C.	1, C.
.207 Mathematics			
Ratio, proportion, decimals, fractions, and percentages	3, 2, 1, C.	3, 2, 1, C.	3, 2, 1, C.
.208 Electrical Shop			
Organization and opreation of the electrical shop aboard own ship and the procedure for obtaining tools and materials.	3, 2, 1, C.	3, 2, 1, C.	3, 2, 1, C.
.209 Standards			
Standards and specifications applicable to shipboard electrical work, as set forth in *Bureau of Ships Manual.*	3, 2, 1, C.	3, 2, 1, C.	3, 2, 1, C.
.210 Batteries			
Theory of dry cell and storage batteries	3, 2, 1, C.	3, 2, 1, C.	3, 2, 1, C.
.211 Damage Control			
Electrical damage control procedures; preventive measures used in the installation, operation, and maintenance of electrical apparatus.	3, 2, 1, C.	3, 2, 1, C.	3, 2, 1, C.
All emergency power and lighting systems, including methods of cross connections and substitution.	2, 1, C.	2, 1, C.	2, 1, C.
.212 I. C. Systems			
Fundamentals of IC and gyro systems aboard naval vessels.	1, C.	1, C.	1, C.
.213 Safety Precautions			
Safety precautions to be observe when working on machinery, electrical equipment, and boats.	3, 2, 1, C.	3, 2, 1, C.	3, 2, 1, C.
214 Publications			
Portions of Bureau of Ships Manual applicable to shipboard electrical work.	1, C.	1, C.	1, C.
.215 Organization			
Organization of Electrical Division in own ship	3, 2, 1, C.	3, 2, 1, C.	3, 2, 1, C.
Organization of Engineering Department of ship to which attached and the relationship of other ratings to electrical work.	1, C.	1, C.	1, C.

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